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TRANSLATION

OF THE

SÚRYA SIDDHÁNTA

BY

PUNDIT BÁPÚ DEVA SÁSTRI,

AND OF THE

SIDDHÁNTA ŚIROMANI

BY THE LATE

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TRANSLATION

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SU'RYA SIDDHA'NTA.

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TRANSLATION OF SU'RYA-SIDDHANTA.

CHAPTER I.

Called MADHYA-GATI *which treats of the Rules for finding the mean places of the planets.*

Invocation.

1. Salutation to that Supreme Being which is of inconceivable and imperceptible form, void of properties (of all created things), the external source of wisdom and happiness, and the supporter of the whole world in the shapes (of BRAHMÁ, VISHNU and SIVA.)

Introductory.

2 & 3. Some time before the end of the KRITA YUGA, a great Demon named MAYA, being desirous of obtaining the sound, secret, excellent, sacred and complete knowledge of Astronomy, which is the best of the six sciences subordinate to the VEDA, practised the most difficult penance, the worship of the Sun.

4. The self-delightful Sun, being gratified at such (difficult) penance of MAYA, bestowed on him the knowledge of the science of Astronomy which he was inquiring after.

The illustrious Sun said.

5. (O MAYA,) I am informed of your intention (of attaining the knowledge of the science of Astronomy) and pleased with your penance. I, therefore will grant you the great knowledge of Astronomy which treats of time.

6. (But since) nobody can bear my light and I have no time to teach you (the science,) this man who partakes of my nature will impart to you the whole of the science.

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7. The God Sun, having thus spoken to, and ordered the man born from himself (to teach MAYA), disappeared. That man spoke to MAYA, who stood bending and folding his hands close to his forehead, in the following manner.

8. (O MAYA), hear attentively the excellent knowledge (of the science of Astronomy) which the Sun himself formerly taught to the great saints in each of the YUGAS.

9. I teach you the same ancient science, which the Sun himself formerly taught. (But) the difference (between the present and the ancient works) is caused only by time, on account of the revolution of the YUGAS.

Kinds of time.

10. Time is of two kinds; the first (is continuous and endless which) destroys all animate and inanimate things (which is also the cause of creation and preservation), the second is that which can be known. This (latter kind of time) is also of two kinds; the one is called MÚRTA (measurable) and the other is AMÚRTA (immeasurable, by reason of bulkiness and smallness respectively).

Pala and Ghaṭiká.

11. The time called MÚRTA, begins with PRÁṆA (a portion of time which contains four seconds,) and the time called AMÚRTA begins with TRUṬI (a very small portion of time which is the $\frac{1}{33750}$th part of a second.) The time which contains six PRÁṆAS is called a PALA, and that which contains sixty PALAS is called a GHAṬIKÁ.

Day and Month.

12. The time, which contains sixty GHAṬIKÁS is called a NÁKSHATRA AHORÁTRA (a sidereal day and night) and a NÁKSHATRA MÁSA (a sidereal month) consists of thirty NÁKSHATRA AHORÁTRAS. Thirty SÁVANA (terrestrial) days (a terrestrial day being reckoned from sun-rise to sun-rise) make a SÁVANA month.

The lunar and solar month and the Divine Day.

13. Thirty lunar days make a lunar month, and a solar month is the time which the Sun requires to move from

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one sign* of the Zodiac to the next. A solar year consists of twelve solar months; and this is called a day of the Gods.

The length of the year of the Gods and Demons.

14. An AHORÁTRA (day and night) of the Gods and that of the Demons are mutually the reverse of each other, (viz. a day of the Gods is the night of the Demons; and conversly, a night of the Gods is the day of the Demons). Sixty AHORÁTRAS, multiplied by six, make a year of the Gods and Demons.

The length of a great YUGA.

15 & 16. The time containing twelve thousand years of the Gods is called a CHATURYUGA (the aggregate of the four YUGAS, KṚITA, TRETÁ, DWÁPARA and KALI).

These four YUGAS including their SANDHYÁ† and SANDHYÁNS'A contain 4,320,000 solar years.

The numbers of years included in these four small YUGAS are proportional to the numbers of the legs of DHARMA‡ (virtue personified).

The length of the four small YUGAS.

17. The tenth part of 4,320,000 the number of years in a great YUGA, multiplied by 4, 3, 2, 1 respectively make up the years of each of the four YUGAS, KṚITA and others, the years of each YUGA include their own sixth part, which is collectively the number of years of SANDHYÁ and SANDHYÁNS'A, (the periods at the commencement and expiration of each YUGA).

The length of a period called MANU and that of its SANDHI.

18. (According to the technicality of the time called MÚRTA,) 71 great YUGAS (containing 306,720,000 solar years) constitute a MANWANTARA (a period from the beginning of a

* It is to be observed here that the signs Aries, Taurus, &c., are reckoned from the star REVATÍ (ζ Piscium,) and a solar year corresponds to a sidereal year. B. D.

† These two words will be explained in the sequel. B. D.

‡ It is stated that Dharma stands with four legs in the KṚITA, with three legs in the TRETÁ, with two legs in the DWÁPARA and with one leg in the KALI. Therefore the number of the years of the KṚITA, TRETÁ, DWÁPARA, and KALI are proportional to 4, 3, 2 and 1 respectively. B. D.

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Manu to its end) and at the end of it, 1,728,000 the whole number of the (solar) years of the KṚITA, is called its SANDHI; and it is the time when a universal deluge happens.

The length of a KALPA.

19. Fourteen such MANUS with their SANDHIS (as mentioned before), constitute a KALPA, at the beginning of which is the fifteenth SANDHI which contains as many years as a KRÍTA does.

The lengths of a day and night of the God BRAHMÁ.

20. Thus a thousand of the great YUGAS make a KALPA, a period which destroys the whole world. It is a day of the God BRAHMÁ, and his night is equal to his day.

The period of his life and that of his passed age.

21. And the age of BRAHMÁ consists of a hundred years—according to the enumeration of day and night (mentioned in the preceding S'LOKA). One half of his age has elapsed, and this present KALPA is the first in the remaining half of his age.

22. Out of this present KALPA six MANUS with their SANDHIS, and twenty-seven YUGAS of the seventh Manu called VAIVASWATA have passed away.

23. Of the twenty-eighth great YUGA, the KṚITA YUGA has passed away. Let (a calculator,) reckoning the time from the end of the KṚITA compute the number of years passed.

24. 47,400 years of the Gods have elapsed in the creation of the God BRAHMÁ, of animate and inanimate things, of the planets, stars, Gods, Demons, &c.

How the planets move eastward.

25. Now the planets (such as the Sun) being on their orbits, go very rapidly and continually with the stars towards the west and hang down (from their places towards east) at an equal distance, (i. e. they describe equal spaces daily towards the east,)* as if overpowered by the stars (by reason of their very rapid motion caused by the air called PRAVAHA.)

* The Hindu Astronomers suppose that all the planets move in their orbits with the same velocity. B. D.

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26. Therefore, the motions of the planets appear towards the east, and their daily motions determined by their revolutions (by applying the rule of proportion to them) are unequal to each other, in consequence of the circumferences of their orbits; and by this unequal motion, they pass the signs (of the Zodiac.)

Bhagaṇa or a sidereal revolution.

27. The planet which moves rapidly, requires a short time, to pass the signs (of the Zodiac,) and the planet that moves slowly, passes the signs (of the Zodiac) in a long time. BHAGAṆA means that revolution through the signs (of the Zodiac which a planet makes by passing round) up to the end of the true place of the star called REVÁTI (ζ Piscium, from which end they set out.)

The circular measures.

28. Sixty VIKALÁS (seconds) make a Kalá (a minute) and sixty minutes constitute an ANS'A (a degree.) A RÁSÍ (a sign) consists of thirty degrees and just twelve RÁS'IS (signs) make a Bhagaṇa (revolution.)

The number of revolutions of the Sun, Mercury, Venus, and the S'íghrochcha of Mars, Saturn and Jupiter in a great YUGA.

29. In a great YUGA each of the planets, the Sun, Mercury, Venus and the S'ÍGHROCHCHA (i. e. the farthest point from the centre of the Earth in the orbit of each of the planets) of Mars, Saturn and Jupiter moving towards the east make 4,320,000 revolutions (about the Earth).

Of Moon and Mars.

30. There are 57,753,336 revolutions of the Moon and 2,296,832 revolutions of the planet Mars.

Of Mercury's S'íghrochcha and Jupiter.

31. There are 17,937,060 revolutions of the S'ÍGHROCHCHA of the planet Mercury* and 364,220 revolutions of the planet Jupiter.

* The revolutions of the Síghrochchas of Mercury and Venus correspond to their revolutions about the Sun. B. D.

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Of Venus's S'íghrochcha and of Saturn.

32. There are 7,022,376 revolutions of the S'ÍGHROCHCHA of the planet Venus* and 146,568 revolutions of the planet Saturn.

Of Moon's Apogee and Node.

33. In a great YUGA, there are 488,203 revolutions of the Moon's MANDOCHCHA (apogee,) and the number of the retrograde revolutions of the Moon's ascending node is 232,238.

Number of sidereal revolutions and the mode of finding the number of risings of the planets in a YUGA.

34. There are 1,582,237,828 sidereal revolutions in a great YUGA (a sidereal revolution is the time from one rising of a star to the next at the equator and it is a sidereal day as mentioned in the twelfth S'LOKA.) These sidereal revolutions diminished by each planet's own revolutions (before mentioned) are its own risings in a great YUGA.

The mode of finding the No. of Lunar months and that of the additive months in a YUGA.

35. The number of Lunar months is equal to the difference between the revolutions of the Moon and those of the Sun; and the remainder of the Lunar Months lessened by the Solar months is the number of ADHIMÁSAS (additive months.)

The mode of finding the No. of subtractive days in a YUGA and the definition of a terrestrial day.

36. If the SÁVANA (terrestrial) days be subtracted from the Lunar days, the remainder constitute the days called the TITHI-KSHAYA (subtractive days.) There the SÁVANA days are those in which a SÁVANA day or terrestrial† day is equal to the time from sun-rise to sun-rise (at the equator).

No. of terrestrial and lunar days.

37. There are 1,577,917,828 terrestrial days and 1,603,000,080 lunar days in a great YUGA.

* The revolutions of the Sighrochchas of Mercury and Venus correspond to their revolutions about the Sun. B. D.

† A terrestrial day is that which the English call a solar day. B. D.

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No. additive months and that of subtractive days.

38. (In a great YUGA) there are 1,593,336 additive months and 25,082,252 subtractive days.

No. of Solar months in a YUGA and the way to know the No. of terrestrial days.

39. There are 51,840,000 Solar months in a great YUGA, and the terrestrial days are the sidereal days diminished by the Sun's revolutions.

40. The revolutions of the planets, the additive months, the subtractive days, the sidereal days, the lunar days and the terrestrial days (mentioned above) separately multiplied by 1000 make the revolutions, the additive months &c., in a KALPA, (because a KALPA consists of 1000 great YUGAS.)

Nos. of Revolutions of the Apogees of the planets.

41 & 42. In a KALPA, there are 387 revolutions of the Sun's Apogee (about the Earth), 204 of Mars' apogee, 368 of Mercury's apogee, 900 of Jupiter's apogee, 535 of Venus' apogee and 39 of Saturn's apogee.

Now we proceed to mention the retrograde revolutions of the Nodes (of the planets Mars, &c.)

43 & 44. There are 214, 488, 174, 903, 662 revolutions of the Nodes of the planets Mars, Mercury, Jupiter, Venus and Saturn respectively. We have already mentioned the revolutions of the apogee and node of the Moon.

The number of the solar years elapsed from the time when the planetary motions commenced, to the end of the last Krita YUGA.

45, 46 & 47. Collect together the years of the six MANUS, with their six SANDHIS, and the SANDHI which lies in the beginning of the KALPA, those of twenty-seven great YUGAS of the present MANU named VAIVASWATA and those of the KRITA YUGA; and subtract from the sum, the said number of years of the Gods, reduced to solar years, required (by the God Brahmá) in the creation of the universe, (before the commencement of the planetary montions,) and the remainder 1,953,720,000 is the number of solar years before the end of the KRITA YUGA.

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To find the ÁHARGAṆA or the No. of terrestrial days from the time the planetary motions commenced to the present mid-night.

48. To 1,953,720,000 the number of elapsed years, add the number of years elapsed (from the end of the last KṚÍTA YUGA to the present year;) reduce the sum to months (by multiplying it by 12;) to the result add the number of lunar months from the beginning of the light half of the CHAITRA* (of the current year to the present lunar month.)

49. Write down the result separately; multiply it by the number of additive months (in a YUGA) and divide the product by the number of solar months (in a YUGA); the quotient, (without the remainder,) will be the elapsed additive months. Add the quotient (without the remainder) to the said result, reduce the sum to days (by multiplying it by thirty) and increase it by the number of (lunar) days (passed of the present lunar month).

50 and 51. Write down the amount in two places; (in one place,) multiply it by the number of subtractive days (in a YUGA); divide the product by the number of lunar days (in a YUGA) and the quotient (without the remainder) will be the number of elapsed subtractive days. Take the number of these days from the amount (which is written in the other place) and the remainder will be the number of elapsed terrestrial days (from the time, when the planetary motions commenced) to the present midnight at LANKÁ.†

* That lunar month which ends, when the Sun is in MESHA (stellar Aries) the first sign of the Zodiac, is called CHAITRA, and that which terminates when the Sun is in VRISHABHA (Taurus) the second sign of the Zodiac, is called VAIS'ÁKHA and so on. Thus the lunar months corresponding to the twelve signs Mesha (Aries,) VRISHABHA (Taurus,) MITHUNA (GEMINI,) KARKA (Cancer,) SINHA (Leo,) KANYÁ (Virgo,) TULÁ (Libra,) VRIS'CHIKA (Scorpio,) DHANU (Sagittarius,) MAKARA (Capricornus,) KUMBHA (Aquarius) and MÍNA (Pisces,) are CHAITRA, VAIS'ÁKHA, JYESHṬHA, ÁSHÁḌHA, S'RÁVAṆA, BHÁDRAPADA, ÁS'WINA, KÁRTIKA, MÁRGAS'ÍRSHA, PAUSHA, MÁGHA and PHÁLGUNA.

If two lunar months terminate when the Sun is only in one sign of the Zodiac, the second of these is called ADHIMÁSA (an additive or intercalary month.) The 30th part of a lunar month is called Tithi (a lunar day.) B. D.

† The proof of the process for finding the AHARGANA stated in the S'LOKAS from 48th to 51st will be clearly understood from the following statement.

In order to find the AHARGAṆA, let the number of the Solar years elapsed be multiplied by 12; and the product is the number of elapsed solar months to the last mean MESHA SANKRÁNTI (i. e. the time when the mean Sun enters the first stellar sign of the Zodiac called stellar Aries;) to this let the number of passed

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From the number of these elapsed days, the Rulers of the present day month and year can be known (by reckoning the order of them) from the Sun.

To find the Ruler of the present day.

Divide the number of elapsed terrestrial days by 7, and reckoning the remainder from the sun-day, the Ruler of the present day will be found.

To find the Rulers of the present terrestrial month and year.

52. Divide the number of elapsed terrestrial days by the number of days in a month and by that in a year (i. e. by 30 and 360) multiply the quotients (rejecting the remainders) by 2 and 3 respectively, and increase the products by 1. Divide the results by 7, and reckoning (the order of the Rulers) from the Sun, the remainders will give the Rulers of the present (terrestrial) month and year respectively.

lunar months CHAITRA, &c., considering them as solar, be added: the sum is the elapsed solar months up to the time when the Sun enters the stellar sign of the Zodiac corresponding to the present lunar month. To make these solar months lunar, let the elapsed additive months be determined by proportion in the following manner.

As the number of solar months in a YUGA
: the number of additive months in that period
: : the number of solar months just found
: the number of additive months elapsed.

If these additive months with their remainder be added to the solar months elapsed, the sum will be the number of lunar months to the end of the solar month; but we require it to the end of the last lunar month. And as the remainder of the additive months lies between the end of the lunar month and that of its corresponding solar month, let the whole number of additive months, without the remainder, be added to the solar months elapsed; and the sum is the number of the lunar months elapsed to the end of the last lunar month.

This number of lunar months elapsed, multiplied by 30 and increased by the number of the passed lunar days of the present lunar month, is the number of lunar days elapsed. To make these lunar days terrestrial, the elapsed subtractive days should be determined by proportion as follows.

As the number of lunar days in a YUGA
: the number of subtractive days in that period
: : the number of lunar days just found
: the number of subtractive days elapsed.

If these subtractive days be subtracted with their remainder from the lunar days, the difference will be the number of terrestrial days elapsed to the end of the last lunar day; but it is required to the present mid-night. As the remainder of the terrestrial days lies between the end of the lunar day and the mid-night, the whole number of the subtractive days, (without the remainder) should be subtracted from the lunar days elapsed, and the difference is, of course, the number of terrestrial days elapsed from the time, when planetary motions commenced, to the present mid-night at LANKÁ. B. D.

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To find the mean places of the planets at a given midnight at LANKÁ.

53. Multiply the number of elapsed terrestrial days by the number of a planet's revolutions (in a KALPA); divide the product by the number of terrestrial days (in a KALPA); and the quotient will be the elapsed revolutions, signs, degrees &c. of the planet. Thus the mean place of each of the planets can be found.

To find the places of the S'íghrochchas, apogees and nodes of the planets.

54. In the same way, the mean places of the S'ÍGHROCHCHA and MANDOCHCHA (apogee) whose direct revolutions (in a KALPA) are mentioned before, and those of the nodes of the planets can be found. But the places of the nodes, thus found, must be subtracted from twelve signs, because their motions are contrary to the order of the signs.

To find the present SAMVATSARA.

55. Multiply the number of elapsed revolutions of Jupiter by 12; to the product add the number of the signs from the stellar Aries to that occupied by Jupiter; divide the amount by 60, and reckoning the remainder from VIJAYA,* you will find the present SAMVATSARA.

An easy method for finding the mean places of the planets.

56. These processes are mentioned (from 45th S'LOKA to 54th) in detail, but, for convenience' sake, let (an astronomer) computing the elapsed terrestrial days from the beginning of the TRETÁ YUGA, find easily the mean places of the planets.

57. At the end of this KRÍTA YUGA the mean places of all the planets, except their nodes and apogees, coincide with each other in the first point of stellar Aries.

58. (At the same instant) the place of the Moon's apogee=nine signs, her ascending node=six signs, and the places of the other slow moving apogees and nodes, whose revolutions are mentioned before, are not without degrees (i. e. they contain some signs and also degrees).

* Astrologers reckon 60 SAMVATSARAS, VIJAYA &c., which answer successively to the periods required by mean Jupiter to move from one sign to the next. B. D.

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The lengths of the Earth's diameter and its circumference.

59. The diameter of the Earth is 1600 YOJANAS. Multiply the square of the diameter by 10, the square-root of the product will be the circumference of the Earth.

The rectified circumference of the Earth, and DES'ÁNTARA* correction in minutes.

60. The Earth's circumference multiplied by the sine of co-latitude (of the given place) and divided by the radius is the SPHUṬA or rectified circumference (i. e. the parallel of latitude) at that place.

Multiply the daily motion (in minutes) by the distance of the given place from the Middle Line of the Earth, and divide the product by the rectified circumference of the Earth.

61. Subtract the quotient in minutes from the place of the planet (which is found at the mid-night of LANKÁ, as mentioned in S'LOKA 53,) if the given place be east of the Middle Line, but if it be west, add the quotient to it, and (you will get) the planet's place at (the mid-night of) the given place.

Middle Line of the Earth.

62. (The cities named) ROHÍTAKA, UJJAYINÍ, KURUKSHETRA &c. are at the line between LANKÁ and the north pole of the Earth, (this line is called the Middle Line of the Earth.)

To find the terrestrial longitude of a place.

63, 64 and 65. At the given place if the Moon's total darkness (in her eclipse) begins or ends after the instant when it begins or ends at the Middle Line of the Earth, then the given place is east of the Middle Line, (but if it begins or ends) before the instant (when it begins or ends at the Middle Line, then) the given place is west of the Middle Line.

Find the difference in GHAṬIKÁs between the times (of the beginnings or ends of the Moon's total darkness at the given place and the mid-night, which difference is called the DES'ÁNTARA GHAṬIKÁS.)

* DES'ÁNTARA is the correction necessary to be applied to the place of a planet in consequence of the longitude of a place, reckoned from the Middle Line of the Earth or the Meridian of LANKÁ. B. D.

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Multiply the rectified circumference of the Earth by this difference and divide the product by 60. The quotient will be the east or west distance (in YOJANAS) of the given place from the Middle Line.

Apply the minutes, found by this distance, to the places of the planets (as directed before in S'LOKAS 60 and 61).

To find the instant when a day of the week begins.

66. A day of the week begins at the DES'ÁNTARA GHAṬIKÁS after or before the mid-night at the given place according as it is east or west of the Middle Line.

To find the mean place of a planet at a given time.

67. (If you want to know the place of a planet at a given time after or before a given mid-night,) multiply the daily motion of the planet by the given time in GHAṬIKÁS, divide the product by 60, and add or subtract the quotient, in minutes, to or from the place of the planet found at the given (mid-night,) and you have the place of the planet at the given time after or before the given mid-night. The place of the planet, thus found, is called its TÁTKÁLIKA or instantaneous place.

68. The Moon's deflection to the north and south from the end of the declination of her corresponding point at the Ecliptic is caused by her node. The measure of her greatest deflection is equal to the $\frac{1}{80}$th part of the minutes in a circle.

69. The measures of the greatest deflections of Jupiter and Mars caused by their nodes are respectively $\frac{2}{9}$ and $\frac{3}{9}$ of that of the Moon, and that of Mercury, Venus and Saturn is $\frac{4}{9}$ of the Moon's greatest deflection.

70. Thus the mean greatest latitudes of the Moon, Mars, Mercury, Jupiter, Venus and Saturn are declared to be 270, 90, 120, 60, 120 and 120 minutes respectively.

End of the 1st chapter of SÚRYA-SIDDHÁNTA called MADHYÁGÁTI (which treats of the Rules for finding the mean places of the planets.)

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CHAPTER II.

Called SPHUṬA-GATI *which treats of the Rules for finding the true places of the planets.*

Cause of the planetary motions.

1. The Deities, invisible (to human sight), named S'ÍGHROCHCHA, MANDOCHCHA (Apogees) and PÁTA (Nodes,) consisting of (continuous and endless) time, being situated at the ecliptic, produce the motions of the planets.

2. The Deities, (S'ÍGHROCHCHA and MANDOCHCHA) attract the planets (from their uniform course) fastened by the reins of winds borne by the Deities towards themselves to the east or the west, with their right or left hands according as they are to their right or left.*

3. (Besides this) a (great) wind called PRAVAHA carries the planets (westward) which are also attracted towards their apogees. Thus the planets being attracted (at once) to the east and west get the various motions.

4. The Deity called UCHCHA (apogee) draws the planet to the east or west (from its uniform progress) according as the Deity is east or west of the planet at a distance less than six signs.

5. As many degrees &c., as the planets, being attracted by their apogees, move to the east or the west, so many are called additive or subtractive (to or from their mean places).

6. In the same way, the Deity node named RÁHU by its power deflects the planet, such as the Moon, to the north or to the south from (the end of) the declination (of its corresponding

* The place of a planet rectified by the 1st or 2nd equation is nearer to its higher apsis (MANDOCHCHA or S'IGHROCHCHA) in its orbit, than the planet's unrectified place. The cause of this is that the Deities have hands furnished with reins of winds and by them they attract the planet towards themselves.
This will explain the meaning of the 2nd S'LOKA. B. D.

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point at the ecliptic). This deflection is called VIKSHEPA (celestial latitude).

7. The Deity node draws the planet to the north or to the south (from the ecliptic) according as the node is west or east of the planet at a distance less than six signs.

8. (But in respect of Mercury and Venus) when their PÁTAS (or nodes) are in the same direction at the same distance (as mentioned in the preceding SLOKA) from their S'ÍGHROCHCHAS, they deflect in the same manner (as mentioned before) by the attractions of their S'ÍGHROCHCHAS.

9. The attraction of the Sun (by its apogee) is very small by reason of the bulkiness of its body, but that of the Moon is greater than that of the Sun, on account of the smallness of the Moon's body.

10. As the bodies of the (five) minor planets, Mars, &c. are very small, they are attracted by the Deities S'ÍGHROCHCHA and MANDOCHCHA very violently.

11. And for this reason, the additive or subtractive equation of the minor planets caused by their movement (which is produced by the attraction by their UCHCHAS) is very great. Thus, the minor planets, being attracted by their S'ÍGHROCHCHA and MANDOCHCHA and carried by the wind PRAVAHA, move in the heavens.

Kinds of motion.

12. (And therefore) the motion of the planets is of eight kinds, i. e.

I. VAKRÁ (decreasing retrograde motion).

II. ATIVAKRÁ (increasing retrograde motion).

III. VIKALÁ (stationary).

IV. MANDÁ (increasing direct motion less than the mean motion).

V. MANDATARÁ (decreasing direct motion less than the mean motion).

VI. SAMÁ (mean motion).

VII. S'ÍGHRATARÁ or ATIS'ÍGHRÁ (increasing direct motion greater than the mean motion).

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VIII. S'ÍGHRA (decreasing direct motion greater than the mean motion).

13. Of these kinds, the five motions* ATIS'ÍGHRA, S'ÍGHRA, MANDA, MANDATARA and SAMA are direct and the two motions VAKRA and ATIVAKRA are retrograde.

14. (Now) I explain carefully the Rules for finding the true places (of the planets) in such a manner that the places found by the Rules coincide with those, determined by observation, of the planets which move constantly with various motions.

The Rule for finding the sines for every $3\frac{3}{4}°$ in a quadrant of the circle whose Radius=3438.

15. The eighth part of the number of minutes contained in a sign (i. e. 1800) is the first sine. Divide the first sine by itself, subtract the quotient from that sine, and add the remainder to that sine : the sum will be the second sine.

16. In the same manner, divide successively the sines (found) by the first sine ; subtract (the sum of) the quotients from the divisor and add the remainder to the sine last found and the sum will be the next sine.* Thus you will get twenty-

* This method is proved thus.

Let

$$\begin{aligned} \sin. A - \sin. O &= d_1 ; \\ \sin. 2A - \sin. A &= d_2 ; \\ \sin. 3A - \sin. 2A &= d_3 ; \\ \&c. &= \&c. \\ \sin. nA - \sin. (n-1)A &= d_n ; \\ \sin (n+1)A - \sin. nA &= d_n + 1. \end{aligned}$$

Then since

$$\begin{aligned} d_1 - d_2 &= 2 \text{ vers } A. \sin A \div R ; \\ d_2 - d_3 &= 2 \text{ vers } A. \sin 2A \div R ; \\ d_3 - d_4 &= 2 \text{ vers } A. \sin 3A \div R ; \\ \&c. &= \&c. \\ d_n - d_{n+1} &= 2 \text{ vers } A. \sin nA \div R ; \end{aligned}$$

we have by addition

$$d_1 - d_{n+1} = \frac{2 \text{ vers } A}{R} (\sin. A + \sin. 2A + \ldots\ldots + \sin. nA) \text{ or,}$$

$$\sin. A + \sin. nA - \sin. (n+1) A = \frac{2 \text{ vers } A}{R} (\sin A + \sin. 2A \ldots\ldots + \sin. nA)$$

$$\therefore \sin. (n+1) A = \sin. nA + \sin. A$$

$$- \frac{2 \text{ vers } A}{R} (\sin. A + \sin. 2A \ldots\ldots + \sin. nA.)$$

Here, $A = 3° 45'$, $\therefore \frac{2 \text{ vers } A}{R} = .0042822 = \frac{1}{233.5}$, which is roughly given in the text $= \frac{1}{225}$.

four sines (in a quadrant of a circle whose radius is 3438). These are as follows.

The sines.

17 to 22. 225, 449, 671, 890, 1105, 1315, 1520, 1719, 1910, 2093, 2267, 2431, 2585, 2728, 2859, 2978, 3084, 3177, 3256, 3321, 3372, 3409, 3431, 3438.

Subtract these sines separately from the Radius 3438 in the inverse order, the remainders will be the versed sines (for every 3¾°).

The versed sines.

23 to 27. There are 7, 29, 66, 117, 182, 261, 354, 460, 579, 710, 853, 1007, 1171, 1345, 1528, 1719, 1918, 2123, 2333, 2548, 2767, 2989, 3213, 3438, versed sines (in a quadrant).

28. The sine of the (mean) greatest declination, (of each of the planets)=1307 (the sine of 24°).

The Rule for finding the planet's (mean) declination from its longitude.

Multiply the sine (of the longitude of a planet) by the said sine 1307; divide the product by the radius 3438; find the arc whose sine is equal to the quotient. This arc is the (mean*) declination (of the planet required).

29. Subtract the place of the planet from those of the MANDOCHCHA† and S'ÍGHROCHCHA: and the remainders‡ are the KENDRAS. From the KENDRA determine the quadrant (in which the Kendra ends,) and the sines of the BHUJA and KOṬI§ (of the KENDRA).

30. The sine of the BHUJA (of the arc which terminates) in an odd quadrant (i. e. 1st and 3rd,) is the sine of that part of

* The mean declination of a planet is the declination of its corresponding point in the ecliptic: but the Sun's mean declination is the same as his true declination. B. D.

† MANDOCHCHA is equivalent to the higher apsis. The Sun's and Moon's MANDOCHCHAS (higher apsides) are the same as their apogees while the other planets' MANDOCHCHAS are equivalent to their aphelions. B. D.

‡ The first remainder is called the first KENDRA which corresponds with the anomaly, and the second, the second KENDRA which is equivalent to the commutation added to or subtracted from 180° as the second KENDRA is greater or less than 180°. B. D.

§ The BHUJA of any given arc is that arc, less than 90°, the sine of which is equal to the sine of that given arc; and the KOṬI of any arc is the complement of the BHUJA of that arc. B. D.

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the given arc which falls in the quadrant where it terminates, but the sine of the KOṬI (of that arc) is the sine of that arc which it wants to complete the quadrant where the given arc ends; and the sine of the BHUJA (of the arc) which ends in an even quadrant (i. e. 2nd and 4th) is the sine of that arc which it wants to complete the quadrant where the given arc ends; but the sine of the KOṬI (of that arc) is the sine of that part of the given arc which falls in that quadrant where it terminates.

To find the sine of the given degrees &c.

31. (Reduce the given degrees &c., to minutes.) Divide the minutes by 225: and the sine (in S'LOKAS 17—22) corresponding to the quotient is called the GATA (the past) sine, (and the next sine is called the GAMYA to be past sine): multiply (the remainder in the said division) by the difference between the GATA and GAMYA sine and divide the product by 225.

32. Add the quotient to the sine past: (the sum will be the sine required). This is the Rule for finding the right sines (of the given degrees &c.) In the same way, the versed sines (of the given degrees &c.) can be found.

Given the sine to find its arc.

33. Subtract the (next less) sine (from the given sine); multiply the remainder by 225 and divide the product by the difference (between the next less and greater sines): add the quotient to the product of 225, and that number (which corresponds to the next less sine); the sum will be (the number of minutes contained in) the arc (required).

Dimensions of the 1st epicycles of the Sun and Moon in degrees of the deferent or concentric.

34. There are fourteen degrees (of the concentric) in the periphery of the MANDA or first epicycle of the Sun, and thirty-two degrees (in the periphery of the 1st epicycle) of the Moon, when these epicycles are described at the end of an even quadrant (of the concentric or on the Line of the Apsides.) But when they are described at the end of an odd quadrant (of the concentric, or on the diameter of the concentric perpendicular to the Line of the Apsides) the degrees in both are

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diminished by twenty minutes; (then the degrees in the periphery of the Sun's epicycle=13° 40′ and in that of the Moon's=31° 40′.)

Dimensions of the 1st epicycles of the Mars &c., in degrees of the concentric.

35. There are 75, 30, 33, 12 and 49, (degrees of the concentric in the peripheries of the first epicycles of Mars, Mercury, Jupiter, Venus and Saturn respectively) at the end of an even quadrant (of the concentric, but) at the end of an odd quadrant, there are 72, 28, 32, 11, 48 (degrees of the concentric.)

Dimensions of the 2nd epicycles of Mars &c.

36. There are 235, 133, 70, 262 and 39 (degrees of the concentric) in the peripheries of the S'íghra or second epicycles of Mars &c., at the end of an even quadrant (of the concentric).

37. At the end of an odd quadrant (of the concentric,) there are 232, 132, 72, 260, 40 degrees of the concentric in the peripheries of the second epicycles of Mars &c.

Given the Kendra of a planet, to find the dimensions of the rectified periphery of the epicycle.

38. Take the difference between the peripheries of epicycles of a planet at the ends of an even and an odd quadrant; multiply it by the sine of the Bhuja (of the given Kendra of the planet,) and divide the product by the radius. Add or subtract the quotient to or from the periphery which is at the end of an even quadrant according as it is less or greater than that which is at the end of an odd quadrant: the result will be the Sphuṭa or rectified periphery (of the epicycle of the planet.)

Given the 1st or 2nd Kendra of a planet, to find the 1st or 2nd Bhuja-phala and Koti-phala and the 1st equation of the planet.

39. Multiply the sines of the Bhuja and Koṭi (of the given 1st and 2nd Kendra of a planet) by the rectified periphery (of the 1st and 2nd epicycle of the planet), and divide the products by the degrees in a circle or 360° (the quotients are called the 1st or 2nd Bhuja-phala and Koṭi-phala respectively). Find the arc whose sine is equal to the 1st Bhuja-phala: the number of the minutes

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contained in this arc is the MANDA-PHALA* (or the 1st equation of the planet.)

To find the 2nd equation of the minor planets Mars &c.

40. Find the 2nd KOṬI-PHALA (from a planet's 2nd KENDRA as mentioned before :) it is to be added to the radius when the Kendra is less than 3 signs or greater than 9 signs, but when the KENDRA is greater than 3 signs and less than 9, (then the 2nd KOṬI-PHALA) is to be subtracted (from the radius).

41. Add the square of the result (just found) to that of the sine of the 2nd BHUJA-PHALA : the square root of the sum is the S'ÍGHRA-KARṆA or 2nd hypothenuse.†

Find the (2nd) BHUJA-PHALA of the planet (as mentioned in S'LOKA 39th ;) multiply it by the radius and divide the product by the 2nd hypothenuse (above found).

42. Find the arc whose sine is equal to the quotient (just found) ; the number of the minutes contained in the arc is called the S'ÍGHRA-PHALA‡ (or 2nd equation of the planet.)

The 2nd equation of Mars &c. is employed in the first and fourth operations (which will be explained in the sequel).

To find the true places of the Sun, the Moon and other planets.

43. (In order to find the true places of the Sun and Moon,) a single operation called MANDA (or operation of finding the first equation,) is to be employed (that is to say, when you want to find the true places of the Sun and Moon, find their first equation and apply it, as will be mentioned in 45th S'LOKA, to their mean places : thus you have the true places of the Sun and Moon).

But in respect of Mars &c. 1st S'ÍGHRA operation (or operation of finding the 2nd equation,) 2nd MANDA operation, 3rd MANDA operation, and 4th S'ÍGHRA operation, are to be employed successively.

* MANDA-PHALA is the same as the equation of the centre of a planet. B. D.

† The S'ÍGHRA-KARṆA or 2nd hypothenuse is equivalent to the distance (in minutes) of the planet from the Earth's centre. B. D.

‡ SÍGHRA-PHALA or 2nd equation is equivalent to the annual parallax of the superior planets ; and the elongation of the inferior planets. B. D.

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44. Find the second equation (from the mean place of a planet:) apply the half of it to the mean place, and (to the result) apply the half of the first equation (found from that result; from the amount) find the 1st equation again, and apply the whole of it to the mean place of the planet and (to that rectified mean place)* apply the whole of the 2nd equation (found from the rectified mean place: thus you will find the true place of the planet).

How the 1st and 2nd equations of the planets are to be applied.

45. In the S'ÍGHRA and MANDA operations, the (second or first) equation of a planet in minutes is to be additive when the (second or first) KENDRA (of the planet) is less than 6 signs; but when it is greater than 6 signs, the (2nd or 1st) equation is to be subtractive.

The BHUJÁNTARA† correction in minutes.

46. Multiply the diurnal motion of a planet by the number of minutes contained in the first equation of the Sun, and divide the product by the number of minutes contained in a circle or 21600′: add or subtract the quotient, in minutes, according as the Sun's equation is additive or subtractive, to or from the place of the planet (which is found from the AHARGAṆA at the mean mid-night at LANKÁ, the result will be the place of the planet at the true mid-night at LANKÁ.)

47. Subtract the diurnal motion of the Apogee of the Moon from her mean diurnal motion; (the remainder will be the Moon's motion from her apogee;) from this remainder find the 1st equation of her motion (by the rule which will be explained further on). This equation is to be subtractive or additive to her mean motion (for finding the true motion of the moon).

* The rectified mean place of a planet is called its MANDA SPHUṬA place. The MANDA-SPHUṬA places of Mars, Jupiter and Saturn correspond with their heliocentric places. B. D.

† The BHUJÁNTARA correction is to be applied to the place of a planet found from the AHARGAṆA for finding the place of the planet at the true mid-night at LANKÁ, arising from that portion of the equation of time which is due to the unequal motion of the Sun in the Ecliptic. B. D.

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Find the true diurnal motions of the Sun and Moon and the MANDA-Sphuṭa motions of the others.

48. In the MANDA operation, find the (first) equation of a planet's diurnal motion from the motion itself, in the same way in which the planet's first equation is found.

(Take the difference between the GATA and GAMYA sines which have been found in finding the sine of the first KENDRA of the planet) ; by the difference between the sines (GATA and GAMYA) multiply the (planet's mean) motion (from its apogee) and divide the product by 225.

49. The quotient multiplied by the (rectified) periphery of the first epicycle of the planet and divided by 360° (becomes the first equation of the planet's motion) in minutes. Add this equation (to the mean diurnal motion of the planet) when the first KENDRA is greater than 3 signs and less than 9; but when the first KENDRA is greater than 9 signs or less than 3, subtract the equation of the motion from it: (thus you have the true diurnal motions of the Sun and Moon, and the MANDA-SPHUTA motions of the others which are equivalent to their heliocentric motions.)

To find the true diurnal motion of a minor planet.

50. Subtract the MANDA-SPHUṬA diurnal motion of a (minor) planet from its S'ÍGHROCHCHA's diurnal motion, and multiply the remainder by the difference between the radius* and the 2nd hypothenuse found in the 4th operation for finding the 2nd equation.

51. Divide the product by the (said) 2nd hypothenuse, add the quotient (to the MANDA-SPHUṬA motion of the planet) when the 2nd hypothenuse is greater than the radius ;* but when it is less than the radius subtract the quotient (from the MANDA-SPHUṬA motion, the result will be the true motion of the planet). (But in the latter case), if the quotient be greater (than the MANDA-SPHUṬA motion,) subtract (the MANDA-SPHUṬA motion from the quotient) ; the remainder will be the retrograde motion of the planet.

* Notes on 50 and 51. Some commentators of the SÚRYA SIDDHÁNTA understand by the term radius the cosine of the 2nd equation found in the 4th operation. B. D.

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The cause of the retrogression of the planets.

52. When a planet is at a great distance (more than 3 signs) from its S'ÍGHROCHCHA and (therefore) its body is attracted by the loose reins (borne by the S'ÍGHROCHCHA,) to its left or right, then the planet's motion becomes retrograde.

When the planets began to retrograde and when they leave their retrogression.

53 and 54. The planets Mars, and others (i. e. Mars, Mercury, Jupiter, Venus and Saturn) get the retrograde motion about the same time when the degrees of (their 2nd) KENDRAS, found in the 4th operation, are equal to 164, 144, 130, 163 and 115 (respectively): and when the degrees of (their 2nd) KENDRAS are equal to the remainders (196, 216, 230, 197 and 245,) found by subtracting the (said) numbers (164, 144, 130, 163 and 115,) from 360° (separately,) the planets leave their retrogression.

55. Venus and Mars (leave their retrogression about the same time) when (their 2nd KENDRA) is equal to 7 signs, on account of the greatness (of the rectified dimension) of their 2nd epicycle: so Jupiter and Mercury (leave their retrogression) when (their 2nd KENDRA)=8 signs, and Saturn leaves its retrogression when (its 2nd KENDRA)=9 signs.

To find the latitude of a planet.

56. Add or subtract the 2nd equations of Mars, Saturn and Jupiter (found in the 4th operation) to or from their nodes according as the 2nd equations applied to the (rectified mean) places of the planets: but in respect of Mercury and Venus add or subtract their 1st equations (found in the 3rd operation, to or from their nodes) according as their 1st equations are subtractive or additive respectively (the results are the rectified nodes).

57. (For the argument of latitude of each of the planets‡ Mars, Jupiter and Saturn) take its rectified node from its true place: but for (the argument of latitude of) Mercury or Venus take its rectified node from its S'ÍGHROCHCHA; find the sine (of

‡ Notes on 56 and 57. It is evident that the argument of latitude of each of the planets, found here, equals the heliocentric place of the planet diminished by the place of its node. B. D.

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the argument of latitude of a planet); multiply it by the (greatest) latitude of the planet (mentioned in S'LOKA 70th of 1st Chapter) and divide the product by the 2nd hypothenuse found in the 4th operation; but in respect of the Moon divide it by the radius: the quotient will be the latitude (of the planet).

To find the true declination of a planet.

58. The (mean) declination (of a planet or the declination found by computation from its corresponding point in the ecliptic) increased or diminished by its latitude, according as they are both of the same or different denominations, becomes the true (declination of the planet). But the Sun's (true declination) is (the same as) his mean declination.

To find the length of a planet's day.

59. Multiply the diurnal motion (in minutes) of a planet by the number of PRÁṆAS which the sign, in which the planet is, takes in its rising (at a given place;) divide the product by 1800′ (the number of minutes which each sign of the ecliptic contains in itself,) add the quotient, in PRÁṆAS, to the number of the PRÁṆAS contained in a (sidereal) day: the sum will be the number of PRÁṆAS contained in the day and night of that planet (at the given place).

Given the declination, to find the radius of the diurnal circle.

60. Find the right and versed sines of the declination (of a planet): take the versed sine (just found) from the radius, the remainder will be the radius of the diurnal circle south or north of the equinoctial. (This radius is called DYUJYÁ).

To find the ascensional difference.

61. Multiply the sine of declination (above found) by the length (in digits) of the equinoctial shadow,* divide the product by 12, the quotient is the KUJYÁ:† The KUJYÁ multiplied by the radius

* The equinoctial shadow is the shadow of a vertical gnomon of 12 digits when the Sun is in the equinoctial at the mid-day at a given place. B. D.

† KUJYÁ is the sine of that arc of a diurnal circle which is intercepted between the Horizon and the six o'clock line. B. D.

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and divided by the DYUJYÁ (above found) becomes the sine of the ascensional difference. The arc of that sine (in minutes) is the ascensional difference in PRÁṆAS.

To find the lengths of the day and night of a planet and a fixed star.

62. Add and subtract the ascensional difference to and from the fourth part of the length of the day and night of the planet (as found in s'LOKA 59) separately, the results will be lengths of the half day and half night respectively of the planet when its declination is north.

63. But when the planet's declination is south, the reverse of this takes place (i. e. the results, just found, will be the lengths of the half night and half day of the planet respectively). (In both cases,) twice the results are the lengths of the day and night (respectively).

In the same way, the lengths of the day and night of any fixed star can be determined from its declination which is to be found by adding or subtracting its latitude to or from the declination (of its corresponding point in the ecliptic).

The BHOGA of a NAKSHATRA and TITHI.

64. The BHA-BHOGA (or the space of a NAKSHATRA or an Asterism) contains 800′ minutes, and the BHOGA of a TITHI (or the space which the Moon describes from the Sun in tithi or lunar day) contains 720′ minutes.

To find the NAKSHATRA in which a planet is at a given time.

The place of a planet, reduced to minutes, divided by the BHABHOGA or 800′, gives the number of those NAKSHATRA or Asterisms (counted from As'WINÍ which are passed by the planet: and the remainder is that portion of the present NAKSHATRA which is passed by the planet.) (This remainder divided) by the diurnal motion (of the planet) gives the quotient in the days, GHATIKÁ'S, &c. which the planet has taken to pass that portion of the present NAKSHATRA.

To find the YOGA* at a given time.

65. The sum of the places of the Sun and Moon (found at a given time,)

* YOGA is a period of time in which the sum of the places of the Sun and Moon increases by 13° 20′ or 800′. B. D.

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reduced to minutes, is to be divided by the BHA-BHOGA (or 800′.) The quotient is the number of the elapsed YOGAS (counted from VISHKARUBHA): (The remainder is called the GATA of the present YOGA, and the BHA-BHOGA (or 800′) diminished by the GATA is called the GAMYA of that YOGA.) The GATA and GAMYA of the present YOGA multiplied by 60 and divided by the sum of the diurnal motions (of the Sun and Moon) become the numbers of the past and to be past GHAṬIKÁS (respectively of the present YOGA at the given time.)

To find the lunar day at a given time.

66. Take the place of the Sun from that of the Moon (found at a given time); divide the remainder, reduced to minutes, by the BHOGA (of a TITHI or 720′; the quotient is the number of the elapsed tithis or lunar days.) (The remainder is the GATA of the present TITHI, and the BHOGA of a TITHI diminished by the GATA is the GAMYA of the present TITHI.) The GATA and GAMYA of the present TITHI, multiplied by 60 and divided by the difference between the diurnal motions (of the Sun and Moon) become the numbers of the past and to be past GHAṬIKÁS (respectively of the present TITHI at the given time).

Invariable KARAṆAS.

67. The four invariable KARAṆAS called S′AKUNI, NÁGA, CHATUSHPADA and KINSTUGHNA (always appropriate to themselves successively the halves of the TITHIS,) from the latter half of the fourteenth TITHI of the dark half (of a lunar month to the first half of the first TITHI of the light half of the next lunar month inclusive).

Variable KARAṆAS.

68. And the seven variable KARAṆAS, BAVA* &c. afterwards succeed each other regularly, through eight repetitions in a (lunar) month.

* 1. BAVA. 2. BÁLVA. 3. KAULAVA. 4. TAITILA. 5. GARAJA. 6. VAṆIJA. 7. BHADRÁ. B. D.

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69. It is to be known that all the KARAṆAS answer successively to half of a TITHI.

(O MAYA,) thus I have explained to you the Rules for finding the true places of the heavenly bodies, the Sun &c.

End of the 2nd Chapter of the SÚRYA-SIDDHÁNTA.

CHAPTER III.

Called the TRIPRAS'NA, *which treats of the Rules for resolving the questions on Time, the position of places, and directions.*

To determine the meridian and east and west lines and the points of the Horizon.

1. On the surface of a stone levelled with water or on the levelled floor of chunam work, describe a circle with a radius of a certain number of digits.

2 and 3. Place the vertical Gnomon of 12 digits at its centre and mark the two points where the shadow (of the Gnomon) before and after noon meets the circumference of the circle: these two points are called the west and the east points (respectively).

Then, draw a line through the TIMI* formed between the

* To draw a line perpendicular to and bisecting the line joining two given points, it is usual to describe two arcs from the two given points as centres with a common radius, intersecting each other in two points: the line passing through the intersecting points is the line required. In this construction, the space contained by the intersecting arcs is called TIMI "a fish," on account of its form. It is evident that the line drawn through the TIMI formed between two given points, must be perpendicular to and bisect the line which joins the given points. B. D.

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(said) east and west points, and it will be the north and south line or the Meridian Line.

4. And thus, draw a line through the TIMI formed between the north and south points of the Meridian Line; this line will be the east and west line.

In the same manner, determine the intermediate directions through the TIMIS formed between the points of the determined directions (east, south &c.).

Given the Gnomonic shadow and its BHUJA, to find the direction of the shadow.

5. (In order to find the direction of a given shadow of the Gnomon at a given time, describe a circle in the plane of the Horizon with a radius whose length is equal to that of the given shadow and at its circumference determine the points of the Horizon, the Meridian and east and west lines as mentioned before:) Then describe a square about the said circle through the lines drawn from the centre (of the circle to the points of the Horizon, in such a manner that the square shall touch the circle at the cardinal points) and in this circle (towards the western or eastern part of it according as the given time is before or after noon), draw a line (as a sine,) equal to BHUJA* (of the given shadow and perpendicular to the east and west line towards the north or south according as the BHUJA is north or south. To the end of this perpendicular, draw a line from the centre). This (line) will denote the direction of the given shadow (at the given time).

6. The line representing the Prime Vertical, the six o'clock line or the equinoctial, passes through the east and west points of the Horizon.

* The distance (in digits) of the end of the shadow of the Gnomon (which is placed at the intersecting point of the Meridian and east and west line) is called the BHUJA (of the shadow north or south according as the end of the shadow is north or south of the east and west line: and the distance of the end of the shadow from the Meridian Line is called the KOṬI (of the shadow) east or west according as the end of the shadow is east or west of the Meridian Line. B. D.

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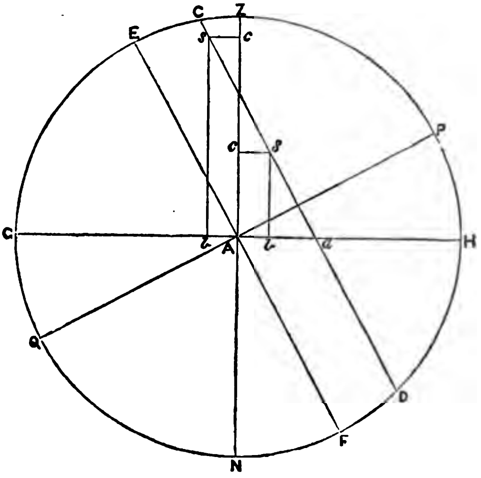
To find the sine of amplitude reduced to the hypothenuse of the given shadow.

7. (In the said circle)* from the east and west line (to its north) at a distance equal to the equinoctial shadow, draw another line parallel to the former; the distance between the end of the



* Note on the 7th S'LOKA.

Let Z G N H be the plane of the Meridian of the given place of north latitude; and in that plane let G A H be the diameter of the Horizon, Z the zenith, P and Q the north and south poles, E A F the diameter of the Equinoctial, P A Q that of the six o'clock line, Z A N that of the Prime vertical, C *a* D that of one of the diurnal circle in which the Sun is supposed to revolve at the given day and *s* the projection of the Sun's place: and let *s c*, *s b* be the perpendiculars to Z N, G H respectively.

Then, A *a* = AGRÁ or the sine of the Sun's amplitude;

S *b* = SÁNKU or the sine of the Sun's altitude;

c s or A *b* = BHUJA or the sine of the distance of the Sun from the Prime Vertical measured on a great circle passing through the Sun and at right angles to the Prime Vertical.

a b = S'ANKUTALA or the distance of the perpendicular drawn from the Sun's place to the horizontal plane, from the line (called the UDAYÁSTA-SÚTRA in Sanskrit) in which the plane of the Horizon intersects that of the diurnal circle: and it is evident from the figure that

$$A\,a = ab \pm A\,b:$$

or AGRÁ = S'ANKUTALA ± BHUJA:

in this the upper or lower sign must evidently be used according as the Sun is north or south of the Prime Vertical.

Now if these AGRÁ, S'ANKUTALA and BHUJA which are in terms of the radius of a great circle, be reduced to the hypothenuse of the gnomonic shadow at the given time, it is clear that the reduced BHUJA will be equal to the distance of the end of the shadow from the east and west line, but the reduced SÁNKUTALA will equal the Equinoctial shadow. It is showed thus:

let R = the radius of a great circle:

h = the hypothenuse of the shadow;

then, $h : R = 12 : s\,b, \therefore s\,b = \dfrac{12\,R}{h}$;

Now, in the triangle *s a b* ∵ ∠ *a s b* = the latitude of the given place;

$$\therefore \frac{a\,b}{s\,b} = \frac{\text{the sine of latitude}}{\text{the cos. of latitude}} = \frac{\text{the Equinoctial shadow}}{12};$$

given shadow and the latter line is equal to the sine of amplitude (reduced to the hypothenuse of the given shadow).

Given the shadow to find its hypothenuse.

8. The square-root of the sum of the squares (of the lengths) of the Gnomon and the given shadow is called the hypothenuse of the shadow: from the square of the hypothenuse subtract the square of the Gnomon; the square-root of the remainder will be equal to the shadow; and the length of the Gnomon is to be known (from the shadow) by the inverse calculation.

The precession of the equinoxes.

9. The circle of Asterisms librates 600 times in a great YUGA (that is to say, all the Asterisms, at first, move westward 27°. Then returning from that limit they reach their former places. Then from those places they move eastward the same number of degrees; and returning thence come again to their own places. Thus they complete one libration or revolution, as it is called. In this way the number of revolutions in a YUGA is 600 which answers to 600,000 in a KALPA).

Multiplying the AHARGAṆA (or the number of elapsed days) by the said revolutions and dividing by the number of terrestrial days in a KALPA; the quotient is the elapsed revolutions, signs, degrees, &c.

10. (Rejecting the revolutions), find the BHUJA of the rest (i. e. signs, degrees &c. as mentioned in S'LOKA 30th of the 2nd Chapter). The BHUJA (just found) multiplied by 3 and divided by 10* gives the degrees &c. called the AYANA (this is the same with the amount† of the precession of the equinoxes).

or $a\,b \times \frac{h}{12\,R} = \frac{\text{the Equinoctial shadow}}{12}$;

$\therefore a\,b \times \frac{h}{R}$ or the reduced S'ANKUTALA = the Equinoctial shadow;

∴ The reduced sine of amplitude
= the Equinoctial shadow ± the reduced BHUJA; this explains the 7th S'LOKA. B. D.

* 27° : 90°. B. D.

† This is the distance of the Stellar Aries from the vernal equinox. B. D.

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Add or subtract the amount of the precession of the equinoxes (according as the asterisms are moving eastward or westward at the given time) to or from the place of a planet: from the result (which is equivalent to the longitude of the planet) find the declination, the shadow of the Gnomon, the the ascensional difference &c.

This motion of the asterisms (or the precession of the equinoxes) will be verified by the actual observation of the Sun when he is at the equinoctial or the solstitial points.

11. According as the Sun's true place found by computation (as stated in the 2nd Chapter) is less or greater than that which is found by observation (i. e. the longitude of the Sun), the circle of asterisms is to the east or west (from its original place) as many degrees as these are in the difference (between the Sun's true place and the longitude).

The equinoctial shadow.

12. At a given place, when the Sun comes to the equinoctial, the shadow (of the Gnomon of 12 digits) cast on the Meridian Line at noon is called the PALABHÁ or the equinoctial shadow (for that place).

Given the equinoctial shadow, to find the co-latitude and latitude.

13. The Radius multiplied by the Gnomon (or 12) and the equinoctial shadow (separately) and divided by the equinoctial hypothenuse* gives the cosine and sine of the latitude (respectively). The arcs of these sines are the co-latitude and the latitude which are always south† (at the given place from whose zenith the equinoctial circle is inclined to the south).

Given the Gnomon's shadow at noon and Sun's declination, to find the latitude of the place.

14 and 15. The BHUJA of the shadow of the Gnomon at noon is the same as the shadow itself. Multiply

* The equinoctial hypothenuse is the hypothenuse of the equinoctial shadow found by taking the square-root of the sum of the squares of the equinoctial shadow and the Gnomon (or 12). B. D.

† The south latitudes of Sanskrit correspond to the north latitudes of the Europeans. B. D.

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the Radius by that BHUJA and divide the product by the hypothenuse of the said shadow; the quotient will be the sine of the zenith distance: the zenith distance, found from that sine in minutes, is north or south according as the BHUJA is south or north respectively (at a given place). Find the sum of the zenith distance and the Sun's declination in minutes when they are both of the same name, but when they are of contrary names, find the difference between them. This sum or difference is the latitude in minutes (at the given place).

To find the equinoctial shadow from the latitude.

16. Find the sine of the latitude, (just found); take the square of that sine from that of the Radius; the square root of the remainder is the cosine of the latitude. The sine of the latitude multiplied by 12 and divided by the cosine of the latitude gives the PALABHÁ or the equinoctial shadow.

Given the latitude of the place and the Sun's zenith distance at noon, to find his declination and longitude.

17. Find the difference between the degrees of the latitude (at a given place) and those of the Sun's zenith distance at noon when they are both of the same name, but when they are of contrary names find the sum of them; the result will be the Sun's declination: multiply its sine by the Radius.

18. Divide the product by the sine of the Sun's greatest declination (or 1397) : find the arc (in signs &c. whose sine is equal to the quotient, just found); this arc will be the longitude of the Sun when he is in the first quarter of the Ecliptic: but when he is in the second or third quarter, subtract or add the signs &c. (contained in the arc) from or to 6 signs; (the remainder or the sum will be the longitude of the Sun).

19. And when the Sun is in the fourth quarter of the Ecliptic subtract the signs &c. (which compose the arc) from 12 signs; the remainder will be the true longitude of the Sun at noon.

(To the longitude, just found, apply the amount of the precession of the equinoxes inversely for the Sun's true place.)

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To find the Sun's mean place from his true place.

(In order to find the mean place of the Sun from his true place above found,) find the 1st equation from the true place of the Sun and apply it inversely to the place repeatedly, the result is the mean place of the Sun (that is, assume the true place as his mean place, find the Sun's first equation from it and add this equation to the true place if the equation be subtractive, but if it be additive, subtract it from the true place; the result will be somewhat nearer to the exact mean place of the Sun at the given noon; assuming this result as the Sun's mean place apply the said mode of calculation, and repeat the process until you get the exact mean place of the Sun).

Given the latitude of the place and the declination of the Sun, to find his zenith distance at noon.

20. Find the sum of the latitude of a given place and the Sun's declination when they are of the same name, but when they are of contrary names find the difference between them; the result will be the zenith distance of the Sun (at noon). Find the sine and cosine of the (found) zenith distance.

Given the Sun's zenith distance at noon, to find the shadow and its hypothenuse.

21. The sine (just found) and the Radius multiplied by the length of the Gnomon in digits (or by 12) and divided by the cosine (above found) give the shadow of the Gnomon and its hypothenuse (respectively) at noon.

Given the Sun's declination and shadow, to find his amplitude and the sine of amplitude reduced.

22. The sine of the Sun's declination multiplied by the equinoctial hypothenuse and divided by 12 gives the sine of the Sun's amplitude. This sine multiplied by the hypothenuse of the Gnomonic shadow at noon, and divided by the Radius, becomes the sine of amplitude reduced to the shadow's hypothenuse.

Given the equinoctial shadow and the reduced sine of amplitude, to find the Bhuja.

23. To this reduced sine of the Sun's amplitude add the equinoctial shadow; the sum will be the north Bhuja (of the shadow at the given time) when the Sun is

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in the southern hemisphere, but when he is in the northern hemisphere, take the reduced sine of amplitude from the equinoctial shadow, and the remainder will be the north Bhuja.

24. In the latter case, when the reduced sine of amplitude is greater than the equinoctial shadow, subtract this shadow from the reduced sine; the remainder will be the south Bhuja between east and west line and the end of the shadow at the given time. Every day the Bhuja at noon equals the Gnomon's shadow at that time.

Given the latitude and the Sun's declination, to find the hypothenuse of the shadow at the time when the Sun reaches the Prime Vertical.

25. Multiply the cosine of the latitude by the Equinoctial shadow or the sine of the latitude by 12; the product (which is the same in both cases) divided by the sine of the Sun's declination gives the hypothenuse of the gnomonic shadow at the time when the Sun reaches the prime vertical.*

Otherwise.

26. When the (Sun's) north declination is less than the latitude, the hypothenuse of the shadow at noon multiplied by the equinoctial shadow and divided by the reduced sine of amplitude at noon, gives the (same) hypothenuse† (which is found in the preceding S'loka).

* This is shown thus,
Let l = latitude of the place;
e = the equinoctial shadow;
d = the sine of the Sun's declination; } when the Sun reaches the prime vertical.
p = ... altitude; }
x = the hypothenuse of the shadow; }
Then, $\sin l : d = R : p$;
and $R : p = x : 12$;

$$\therefore x = \frac{12 \sin l}{d} = \frac{e \cos l}{d}$$ (because $\cos l : \sin l = 12 : l$ and $\therefore e. \cos l = 12 \sin l$).

† This is proved thus.
Let h = the hypothenuse of the shadow at noon;
a = the sine of amplitude reduced to that hyp.

$$\therefore \frac{a R}{h}$$ = the sine of amplitude in terms of the radius.

27. The sine of the declination (of the Sun) multiplied by the radius and divided by the cosine of the latitude becomes the sine of amplitude. Multiply this sine by the hypothenuse of the shadow at a given time and divide the product by the radius: the quantity obtained is the sine of amplitude in digits (reduced to the hypothenuse of the shadow at the given time).

Given the equinoctial shadow and the Sun's amplitude, to find his altitude when situated in the vertical circle of which the azimuth distance is 45°.

28 and 29. Subtract the square of the sine of amplitude from the half of the square of the radius; multiply the remainder by 144; divide the product by the half of the square of the gnomon (i. e. 72) increased by the square of the equinoctial shadow. Let the name of the result be the KARAṆÍ. Let the calculator write down this number (for future reference).

30. Multiply twelve times the equinoctial shadow by the sine of amplitude and divide the product by the former divisor (i. e. 72 added to the square of the equinoctial shadow). Let the result be called the PHALA. Add the square of the KARAṆÍ to the PHALA and take the square-root of the sum.

31 and 32. The square-root, (just found), diminished or increased by the PHALA according as the Sun is south or north of the equinoctial, becomes the Koṇa-s'anku* or the sine of

Then $\frac{aR}{h} : p$ (the sine of the Sun's altitude when he is at the prime vertical) $= \cos l : \sin l = e$ (equinoctial shadow) $: 12$;

$$\therefore \quad p = \frac{12\,aR}{h\,e};$$

and $\therefore p : R = 12 : x$ (the hypothenuse of the Sun's shadow when he reaches the prime vertical):

$$\therefore x = \frac{12\,R}{p} = 12\,R \times \frac{h\,e}{12\,a\,R} = \frac{h\,e}{a};$$ supposing the Sun's declination to undergo no change during the day.

* This is demonstrated thus.
Let e = the equinoctial shadow,
a = the sine of amplitude,
k = the KARAṆÍ,
f = the PHALA,
and x = the KOṆA-S'ANKU.

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altitude of the Sun when situated at an intermediate vertical (intersecting the Horizon at the N. E. and S. W. or N. W. and S. E. points). If the sun be south of the prime vertical, then the KOṆA-S'ANKU will be south-east or south-west, but if he be north of it, then it will be north-east or north-west. The square-root of the difference between the square of the KOṆAS'ANKU and that of the radius, is called the DṚIGJYÁ or the sine of the zenith distance.

33. Multiply the (said) sine of the zenith distance and the radius by 12 and divide the products by the KOṆA-S'ANKU (above found); the quotients will be the shadow (of the gnomon) and its hypothenuse (respectively, when the Sun will come on an intermediate vertical) at the proper place and time.

Then, $12 : e = x : \frac{e}{12} x =$ S'AUKUTALA (as shown in the note on 7th S'LOKA); and since it is manifest from the same note that the S'AUKUTALA applied with the sine of amplitude by addition or subtraction according as the Sun is south or north of the equinoctial, becomes BHUJA (i. e. the sine of the Sun's distance from the prime vertical),

$$\therefore \frac{e}{12} x \pm a = \text{BHUJA};$$

but when the Sun is N. E., N. W., S. E., or S. W., it is equidistant from the prime vertical and the meridian. Therefore the hypothenuse of a right-angled triangle, of which one side is the BHUJA and the other equal to it, is the sine of the zenith distance.

$$\therefore \text{hyp.})^2 = 2 (\frac{e}{12} x \pm a)^2 = \frac{e^2}{72} x^2 \pm \frac{a e}{3} x + 2 a^2.$$

Now, since the square of the sine of the zenith distance added to the square of the sine of the altitude is equal to the square of the radius,

$$\therefore x^2 + \frac{e^2}{72} x^2 \pm \frac{a e}{3} x + 2 a^2 = R^2;$$

$$\text{or } (e^2 + 72) x^2 \pm 24 a e x = 72 R^2 - 144 a^2;$$

$$\therefore x^2 \pm \frac{24 a e}{e^2 + 72} x = \frac{72 R^2 - 144 a^2}{e^2 + 72} = \frac{144 (\frac{1}{2} R^2 - a^2)}{e^2 + 72}.$$

Now, in the foregoing equation it will be observed that the value of the side containing the known quantities is what has been already spoken of under the name of KARAṆÍ, and that the half of the co-efficient of x is what has been already spoken of under the name of PHALA,

$$\therefore x^2 \pm 2 f x = k,$$

which gives $x = \sqrt{f^2 + k} \pm f$. B. D.

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The latitude of the place and the Sun's declination being given, to find the Sun's altitude, Zenith distance &c. at given time from noon.

34. Add or subtract the sine of the ascensional difference to or from the radius according as the Sun is in the northern or southern hemisphere. The result is called the ANTYÁ. From the ANTYÁ subtract the versed sine of the time from noon (reduced to degrees); Multiply the remainder by the cosine of the declination.

35 and 36. Divide the product, (thus found), by the radius; the quotient is called the CHHEDA; the CHHEDA multiplied by the cosine of latitude and divided by the radius becomes the S'ANKU* or the sine of the Sun's altitude (at the given time). Subtract the square of the S'ANKU from that of the radius; the square root of the remainder is DṚIG-JYÁ or the sine of the zenith distance (at the given time). (From the S'ANKU and the DṚIG-JYÁ) find the shadow and its hypothenuse as mentioned before (in S'LOKA 32).

Given the gnomonical shadow and its hypothenuse, to find the time from noon.

Multiply the radius by the given shadow (of the gnomon) and divide the product by the shadow's hypothenuse.

* This will be manifest thus.
Let l = latitude of the place north of the equator;
d = the Sun's declination;
a = the ascensional difference,
t = the time from noon in degrees,
and x = the Sun's altitude.
Then we have the equation which is very common:

$$\sin x = \frac{\cos t.\cos l.\cos d \pm \text{R}.\sin l.\sin d.}{\text{R}^2};$$

$$= \frac{\left(\cos t \pm \dfrac{\tan l.\tan d}{\text{R}}\right)\cos l.\cos d}{\text{R}};$$

$$= \frac{(\cos t \pm \sin a)\cos l \cos d}{\text{R}^2};$$

or $$= \frac{(\text{R} + \sin a - \text{vers}\ t)\cos d}{\text{R}}.\frac{\cos d}{\text{R}}.$$

It is to be observed here, that when the latitude of the place is north, the sin a becomes plus or minus according as the declination is north or south. B. D.

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37. The quotient is the DRIG-JYÁ; the square-root of the square of the radius diminished by that of the DRIG-JYÁ (just found), is the S'ANKU: multiply it by the radius and divide the product by the cosine of latitude (of the place).

38 and 39. The result (thus found) is the CHHEDA; multiply the CHHEDA by the radius; divide the product by the cosine of the declination. Subtract the quotient from the ANTYÁ and take the remainder. From the versed sines (given in S'LOKAS 23—27 of the second chapter) find the arc whose versed sine equals the remainder: The minutes contained in the arc are the PRÁṆAS in the time before or after noon.*

Given the latitude of the place and the reduced sine of amplitude, to find the Sun's declination and longitude.

Multiply the cosine of latitude by the given reduced sine of amplitude and divide the product by the given shadow's hypothenuse (at a given time).

40. The quotient, (thus found), is the sine of the Sun's declination; multiply it by the radius and divide the product by the sine of the greatest declination; find the arc in signs, degrees, &c.; from this arc and that quarter of the ecliptic in which the Sun is situated at the given time the Sun's longitude can be determined (as mentioned before in S'LOKAS 18 and 19 of this Chapter).

To draw a line in which the Gnomonic shadow's end revolves.

41. On any day place a vertical gnomon on an horizontal plane; mark the end of the shadow at three different times on the plane, and describe a circle passing through these points. Then the end of the shadow of that gnomon will revolve in the circumference of this circle through that day.†

* This Rule is the converse of the preceding one. B. D.

† This Rule is refuted by BHÁSKARÁCHÁRYA in his GOLADHYÁYA, and he is right, because the end of the gnomonical shadow revolves in an hyperbola in the places between the arctic and antarctic circles. B. D.

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To find the right ascensions of the first three signs of the Ecliptic.

42. (In order to find the right ascensions of the ends of the three first signs of the ecliptic i. e. Aries, Taurus and Gemini, find the declinations of the said ends) then multiply the sines of one, two, and three sines by the cosine of the greatest declination of the Sun separately, and divide the products by the cosines of the declinations (above found), respectively: The quotients will be the sines of the arcs; find the arcs in minutes. (These arcs will be the right ascensions of the ends of the three first signs of the ecliptic).

To find the rising periods of those signs at the Equator.

43. The number of minutes contained in the first right ascension, (above found), is the number of PRÁṆAS which Aries takes in its rising at LANKÁ (or the equator); then take the first right ascension from the second and the second from the third; the remainders in minutes will denote the numbers of PRÁṆAS in which Taurus and Gemini rise at the equator.

(The numbers of the PRÁṆAS, thus found, contained in the rising periods of Aries, Taurus and Gemini at the equator are) 1670, 1795 and 1935 (respectively).

To find the rising periods of those signs at a given place.

(In order to find the rising periods of the first three signs of the ecliptic at a given place of N. L., find at first the ascensional differences of the ends of the said signs at that place and subtract the first ascensional difference from the second and the second from the third. The first ascensional difference and these remainders are severally called the CHARAKHAṆḌAS of the said signs for the given place). Subtract the CHARAKHAṆḌAS (of the first three signs) for the given place from their rising periods at the equator: the remainders will be the rising periods in PRÁṆAS of the said signs at the given place.

To find the rising periods of the rest.

44. The rising periods of the first three signs of the ecliptic at the Equator successively increased by their CHARAKHAṆḌAS give in

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a contrary order the rising periods of the following three signs (i. e. Cancer, Leo and Vergo). The rising periods of the first 6 signs, thus found, answer in an inverse order to those of the latter six Libra, &c. for the given place.

To find the Horoscope or the point of the ecliptic just rising at a given time from sunrise.

45. From the Sun's longitude ascertained at the given time, find the BHUKTA and BHOGYA times in PRÁṆAS, (in the following manner. Find the sign in which the Sun is and find the BHUKTA degrees or the degrees which the Sun has passed and the BHOGYA degrees or those which he has to pass). Multiply the numbers of the BHUKTA and BHOGYA degrees (separately) by the rising period of the said sign (at the given place) and divide the products by 30. (The first quotient is the BHUKTA time in PRÁṆAS in which the Sun has passed the BHUKTA degrees, and the latter is the BHOGYA time in PRÁṆAS in which he has to pass the BHOGYA degrees.)

46 and 47. From the given time in PRÁṆAS (at the end of which the Horoscope is to be found) subtract the BHOGYA time in PRÁṆAS and the rising periods of the next signs (to that in which the Sun is, as long as you can, then at last, you will find the sign, the rising period of which being greater than the remainder you will not be able to subtract, and which is consequently called the AS'UDDHA sign or the sign incapable of being subtracted, and its rising period the AS'UDDHA rising). Multiply the remainder thus found by 30 and divide the product by the AS'UDDHA rising period: add the quotient, in degrees, to the preceding signs (to the AS'UDDHA sign) reckoned from Aries: (and to the sum apply the amount of the precession of the equinoxes by subtraction or addition according as it will be additive or subtractive): the result, (thus found), will be the place of the Horoscope* at the eastern horizon. If the time at the end of which the Horoscope is to be found,

* Thus there are two processes for finding the Horoscope, one when the given time is after sun-rise and the other when it is before sun-rise, and which are consequently called KRAMA or direct and VYÚLKRAMA or indirect processes respectively. B. D.

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be given before sun-rise, then take the BHUKTA time (above found) and the rising periods of the preceding signs, to that which is occupied by the Sun) in a contrary order from the given time; multiply the remainder by 30 and divide the product by the AS'UDDHA rising period; subtract the quotient, in degrees, from the signs (reckoned from Aries to the AS'UDDHA sign inclusive); the remainder (inversely applied with the amount of the precession of the equinoxes) will be the place of the Horoscope at the eastern horizon.

To find the culminating point of the Ecliptic at the given time from noon.

48. From the time, in GHAṬIKAS, from noon, before or after, the Sun's place found at the given time, and the rising periods of the signs ascertained for the equator, find the arc, in signs, degrees, &c. (intercepted between the Sun and the meridian at the given place) subtract or add the signs &c. (just found) from or to the Sun's place (according as the given time is before or after noon); the result will be the place of the culminating point of the ecliptic (at the given time).

Given the place of the Horoscope and that of the Sun, to find the time from sun-rise.

49. (Of the given place of the Horoscope and that of the Sun), find the BHOGYA time in PRÁṆAS, of the less and the BHUKTA time, in PRÁṆAS of the greater, add together these times and the rising periods of the intermediate signs (between those which are occupied by the Sun and the Horoscope); and you will find the time (from sun-rise at the end of which the given place of the Horoscope is just rising in the eastern horizon).

50. When the given place of the Horoscope is less than that of the Sun, the time (above found) will be before sun-rise, but when it is greater, the time will be after sun-rise.

And when the given place of the Horoscope is greater than that of the Sun increased by 6 signs, the time found (as mentioned before) from the place of the Horoscope and that of the Sun added to 6 signs will be after sun-set.

End of the third Chapter called the TRIPRAS'NA.

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CHAPTER IV.

On the Eclipses of the Moon.

The diameters of the Sun and Moon in YOJANAS and their rectification.

1. The diameter of the Sun's orb is 6,500 YOJANAS and that of the Moon's is 480 YOJANAS.

2 and 3. The diameters of the Sun and Moon multiplied by their true diurnal motions and divided by (their) mean diurnal motions become the SPHUTA or rectified diameters.

To find the Sun's diameter at the Moon and their diameters in minutes.

The rectified diameter of the Sun multiplied by his revolutions (in a KALPA) and divided by the Moon's revolutions (in that cycle), or multiplied by the periphery of the Moon's orbit and divided by that of the Sun, becomes the diameter of the Sun at the Moon's orbit.

The diameter of the Sun at the Moon's orbit and the Moon's rectified diameter divided by 15, give the numbers of minutes contained in the diameters (of the discs of the Sun and the Moon respectively).

To find the diameter of the Earth's shadow at the Moon.

4 and 5. Multiply the true diurnal motion of the Moon by the Earth's diameter (or 1,600) and divide the product by her mean diurnal motion; the quantity obtained is called the SÚCHÍ. Multiply the difference between the Earth's diameter and the rectified diameter of the Sun by the mean diameter of the Moon (or 480) and divide the product by that of the Sun (or 6,500); subtract the quotient from the SÚCHÍ the remainder will be the diameter (in YOJANAS) of the Earth's shadow (at the moon); reduce it to minutes as mentioned before (i. e. by dividing it by 15).

To find the probable times of the occurrences of eclipses.

6. The Earth's shadow (always) remains at the distance of 6 signs from the Sun. When the place of the Moon's ascending node equals the place of the shadow or that of the Sun, there will be an

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eclipse (lunar or solar). Or when that node is beyond or within the place of the shadow or that of the Sun, by some degrees, the same thing will take place.

7. The places of the Sun and the Moon found at the time of the new moon are equal (to each other) in signs, (degrees) &c. and at the instant of the full moon they are at the distance of 6 signs from each other.

To reduce the places of the Sun, the Moon and her ascending node as given at mid-night to the instant of the syzygy.

8. (Find the changes of the places of the Sun, the Moon and her ascending node in the instant from midnight to the instant of the syzygy as mentioned in S'LOKA 67th of 1st Chapter). To the places of the Sun and the Moon (as found at the midnight) apply by subtraction or addition their changes according as the instant of the syzygy is before or after midnight: the results are called the SAMA-KALA places of the Sun and the Moon: But increase the place of the node (at midnight) by its change, if the instant of the syzygy be before midnight, or diminish it if it be after midnight.

What covers the Sun and the Moon in their eclipses.

9. The Moon being like a cloud in a lower sphere covers the Sun (in a solar eclipse); but in a lunar one the Moon moving eastward enters the Earth's shadow and (therefore) the shadow obscures her disc.

To find the magnitude of an eclipse.

10. Take the Moon's latitude (at the time of syzygy) from half the sum of the diameter of that which is to be covered and that of the coverer (in a lunar or solar eclipse); the remainder is the greatest quantity of the eclipsed part of the disc.

To ascertain the occurrence of a total, partial or no eclipse.

11. If this quantity should be greater than the diameter of the disc which is to be eclipsed, the eclipse will be a total one, otherwise it will be partial. But if the Moon's latitude be greater than half the sum (mentioned in the preceding S'LOKA) there cannot be an eclipse.

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To find the half duration of the eclipse and that of the total darkness.

12. Find the halves separately of the sum and difference of the diameter of that which is to be covered and that which is the coverer. Subtract the square of the (Moon's) latitude (as found at the time of the syzygy) severally from the squares of the half sum and the half difference and take the square-roots of the results.

13. These roots multiplied by 60 and divided by the diurnal motion of the Moon from the Sun give the STHITYARDHA the half duration of the Eclipse and MARDÁRDHA the half duration of the total darkness in GHAṬIKÁS (respectively).

To find the exact STHITYARDHA and MARDÁRDHA.

14 and 15. The diurnal motions (of the Sun, the Moon and her ascending node) multiplied by the STHITYARDHA (above found) in GHAṬIKÁS and divided by 60 give their changes in minutes. Then to find the first exact STHITYARDHA, subtract the changes of the Sun and the Moon from their places and add the node's change to its place; from these applied places find the Moon's latitude and the STHITYARDHA. This STHITYARDHA will be somewhat nearer the exact one, from this find the changes and apply the same mode of calculation (as mentioned before) and repeat the process until you get the same STHITYARDHA in every repetition. This STHITYARDHA will be the exact first STHITYARDHA. But to find the latter STHITYARDHA add the changes of the Sun and Moon to their places and subtract the node's change from its place; from these applied places find the Moon's latitude and the STHITYARDHA again and repeat the same process until the exact latter STHITYARDHA be found. In the same manner determine the first and second exact MARDÁRDHAS by repeated calculations.

To find the times of the phases of an eclipse.

16. At the end of the true lunar day (i. e. at the time of the full moon) the middle of the eclipse takes place; this time diminished by the exact first STHITYARDHA leaves the time of the beginning,

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and increased by the latter exact STHITYARDHA gives the time of the end.

17. In the same manner, the time of the middle of a total eclipse diminished and increased (separately) by the exact first and second MARDÁRDHAS gives the times of the beginning and end of the total darkness (respectively).

To find the KOṬI or the portion of the coveror's path from the middle of the eclipse to a given time.

18. Multiply the diurnal motion of the Moon from the Sun by the (first) STHITYARDHA diminished by given GHAṬIKÁS and divide the product by 60, the quotient is the KOṬÍ in minutes (or the perpendicular of the right angled triangle of which the Moon's latitude is the base and the distance between the centres of that which is the coveror and that which is to be covered is the hypothenuse).

19. In an eclipse of the Sun, the KOṬI in minutes (above found,) multiplied by the mean STHITYARDHA and divided by the apparent* STHITYARDHA becomes the SPHUṬA or apparent KOṬI in minutes.

To find the quantity of the eclipsed part at a given time during the first half of an eclipse.

20. The Moon's latitude is the BHUJA (or base) and the square-root of the sum of the squares of the KOṬI and BHUJA is the hypothenuse (of the triangle as mentioned before in S'LOKA 18th). Subtract the hypothenuse from half the sum of the diameters (as stated in S'LOKA 10th); the remainder will be the quantity of the eclipsed part (of the disc) at the time (at which the KOṬI and BHUJA are ascertained).

To find the quantity of the eclipsed part as a given time during the latter half of an eclipse.

21. If it be required to know the KOṬI &c. at a given time after the middle of the eclipse, subtract the GHATIKAS (between the given time and the end of the eclipse) from the second STHITYARDHA; from the remainder find the KOṬI &c. as mentioned before. The obscured part found from the second STHITYARDHA is the portion of the disc yet in obscurity.

* The mean and apparent STHITYARDHAS will be explained in the next chapter. B. D.

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Given the quantity of the eclipsed part, to find its corresponding time.

22 and 23. Subtract the minutes contained in the given eclipsed part from half the sum of the diameter of that which is covered and that which is the coveror; from the square of the remainder subtract the square of the Moon's latitude at that time. The square-root of the remainder is the Koṭi in minutes (in the lunar eclipse). But in the solar one the remainder (thus found) multiplied by the apparent Sthityardhá and divided by the mean Sthityardha gives the Koṭi in minutes. From the Koṭi find the time in Ghatiká's in the same way that you found the Sthityardha (from the square-root as mentioned in S'loka 13). At this time (before or after the middle of the eclipse,) the quantity of the eclipsed part is equal to the given one.

To find the Valanas used in the projection of eclipses.

24. Find the zenith distance* (in the prime vertical of the body which is to be eclipsed), multiply its sine by the sine of the latitude of the place, and divide the product by the radius. Find the arc whose sine is equal to the quotient; the degrees contained in this are called the degrees of the (Áksha or the latitudinal) valana: they are north or south according as the body is in the eastern or western hemisphere of the place.

25. From the place of the (said) body increased by 3 signs find the declination, (which is called Áyana or solstitial valaná). Find the sum or difference of the degrees of this declination and those of the latitudinal valaná, when those valanas are of the same name or of contrary names: (the result is called sphuṭa or true valaná). The sine of the true valaná divided by 70 gives the valaná in digits.†

* The distance of the circle of position (passing through the body) from the zenith of the place is called the zenith distance in the prime vertical of the body. The rough amount of this can be easily found by the following simple proportion.

As half the length of the day of the body
: 90.
: : the time from noon of the body at a given time
: the zenith distance in the prime vertical at the given time. B. D.

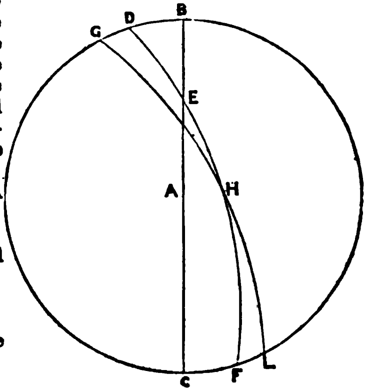
† In the projection of eclipses, after drawing the disc of the body to be eclipsed, the north and south and the east and west lines, which lines will of

To find the ANGULAS or digits contained in the Moon's latitude, diameter, eclipsed part, &c. at a given time during an eclipse.

26. Find the length of the day (of the body which is to be eclipsed as mentioned in S'LOKAS 62 and 63 of the second Chapter): to this length add its half and the UNNATA time (or the half length diminished by

course represent the circle of position passing through the body (supposed on the ecliptic) and the secondary to that circle at the given place, to find the direction of the line representing the ecliptic in the disc of the body on which the knowledge of the exact directions of the phases of the eclipses depends, it is necessary to know the angle formed by the said secondary and the ecliptic. This angle or that arc of a great circle, 90° from the place of the body which is intercepted between the said secondary or the prime vertical and the ecliptic is called the VALANA or variation (of the ecliptic). And as it is very difficult to find this arc at once, it is divided into two parts of which the one is that portion of the great circle (90° from the place of the body) which is intercepted between the Prime vertical and the Equinoctial and the other is that portion of the same circle which is intercepted between the Equinoctial and the ecliptic; these two portions are called the ÁKSHA VALANA and the ÁYANA-VALANA respectively. The ÁKSHA VALANA is called the north or south according as the Equinoctial circle meets the great circle (90° from the place of the body) on the north or south of the prime vertical eastward of the body; and it is evident from this that on the northern latitudes when the body is in the eastern or western hemisphere the ÁKSHA VALANA will be the north or south respectively. And the ÁYANA-VALANA is called the north or south according as the ecliptic meets the said great circle on the north or south of the Equinoctial to the east of the body, and hence it is evident that when the declination of the body's place increased by 3 signs is north or south the ÁYANA-VALANA will be the north or south respectively. From the sum of these VALANAS when they are of the same name or from the difference between them when of contrary names the arc which is intercepted between the prime vertical and the ecliptic is found and hence it will be north or south according as the ecliptic meets the said great circle on the north or south of the prime vertical eastward of the body and it is sometimes called the SPASHTA or rectified VALANA.

Let A be the place of the body; B G C L the great circle 90° from it; B A C the ecliptic; D E F the Equinoctial; E the Equinoctial point; G H L the prime vertical; H the intersecting point of the prime vertical and the Equinoctial, and hence the east or west point of the Horizon and therefore G H equivalent to the zenith distance in the prime vertical.



Then the arc G D = the AKSHA VALANA,

D B = the AYANA-VALANA,

and G B = the SPASHTA or rectified VALANA.

These arcs can be found as follows,

Let L = latitude of the place,

n = the zenith distance in the prime vertical,

l = the longitude of the body,

e = the obliquity of the ecliptic,

d = the declination of the body,

x = the ÁKSHA VALANA,

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the given time from the midday of the body); and by the quotient divide the Moon's latitude, diameter &c. in minutes; the results are the digits contained in the latitude &c.

(End of the fourth Chapter.)

y = the *Áyana-valana*,
and z = the rectified valana.
Then in the spherical triangle D H G
$\sin GDH : \sin DHG = \sin GH : \sin GD$;
here, $\sin GDH = \sin BDE = \cos d$,
$\sin DHG = \sin L$;
and $\sin GH = \sin n$,
$\therefore \cos d : \sin L = \sin n : \sin x$.

$\therefore \sin x$ or the sine of the *Aksha valana* $= \dfrac{\sin L . \sin n}{\cos d}$ in which the Radius is used for cos d in the text

This valana is called north or south according as the point D be north or south of the point G.
And in the triangle D E B
$\sin BDE ; \sin BED = \sin BE : \sin DB$,
or $\cos d : \sin e = \cos l : \sin y$

$\therefore \sin y$ or the sine of the *Áyana valana* $= \dfrac{\sin e \times \cos l}{\cos d}$ in which the Radius is used for cos d in the text.

This valana is called north or south; according as the point B be north or south of the point D.

And the rectified valana $GB = GD + DB$, when the point D lies between the points G and B, but if the point D be beyond them, the rectified valana will be equal to the difference between the Aksha and Ayana valanas. This also is called north or south as the point B be north or south of the point G.

To mark the sine of the spashta valana in the projection of the eclipse it is reduced to the circle whose radius is 49 digits in the text.
i. e. $R : \sin z = 49$: reduced sine of the valana:

$$\therefore \text{ reduced sine of the valana} = \frac{49 \sin z}{R} = \frac{49 \sin z}{3438} = \frac{\sin z}{70}$$

This reduced sine in digits is denominated the valaná in the text. B. D.

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CHAPTER V.

On the Eclipses of the Sun.

Where the parallax in longitude and that in latitude is nothing.

1. There is no parallax in longitude of the Sun when his place equals the place of the nonagesimal. And when the (north) latitude (of the place) and the north declination of the nonagesimal are equal to each other (i. e. when the nonagesimal coincides with the zenith) there will be no parallax in latitude.

2. Now I will explain the rules for finding the parallax in latitude which takes place when the connection of the place and time is different from that which is mentioned (in the preceding S'LOKA,) and the parallax in longitude which arises when the Sun is east or west (of the nonagesimal).

To find the sine of amplitude of the horoscope.

3. At the end of the time of conjunction (from sunrise) in GHATIKA'S find the place of the horoscope through the rising periods at a given place (and apply it with the amount of the precession of the equinoxes.) Its sine multiplied by the sine of greatest declination (or sin 24°) and divided by the cosine of latitude gives a quantity called the UDAYA' (or the sine of amplitude of the horoscope).

To find the sine of the zenith distance of the culminating point of the ecliptic.

4. Then find the place of the culminating point of the ecliptic through the rising periods at the equator as mentioned before, and find the sum of the declination of the culminating point and the latitude of the place when they are of the same name, otherwise find the difference between them.

5. The result (thus found) is the zenith-distance of the culminating point of the ecliptic. The sine of this zenith-distance is called the MADHYAJYA' or the middle sine.

To find the sine und cosine of the zenith-distance of the nonagesimal.

Multiply the MADHYAJYA' by the UDAYA' (above found,) divide the product by the radius and square the quotient.

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6. Subtract the square from the MADHYAJYÁ: the square-root of the remainder is (* nearly equal to) the DRIKSHEPA or the sine of the zenith-distance of the nonagesimal (or the sine of the latitude of the zenith). The square-root of the difference between the squares of the DRIKSHEPA and the radius is the S'ANKU or the sine of the altitude of the nonagesimal. This sine is called the DṚIGGATI.

Otherwise.

7. (Or) the sine and cosine of the zenith-distance (of the culminating point of the Ecliptic,) are the rough DṚIKSHEPA and DṚIGGATI (respectively.)

To find the Moon's parallax in longitude from the Sun reduced to GHAṬIKAS.

Dividing the square of the sine of one sign (or 30°) by the DṚIGGATI (above found,) the quantity obtained is called the CHHEDA or the divisor.

8. The sine of the difference between the place of the Sun and the nonagesimal divided by the CHHEDA gives the Moon's parallax in longitude from the Sun reduced to (sávana) GHAṬIKÁS, whether the Sun be east or west (of the nonagesimal.†)

* For, the square-root of the remainder multiplied by the radius and divided by the cosine of the ecliptical part intercepted between the nonagesimal and the culminating point becomes the exact DṚIKSHEPA or the sine of the latitude of the Zenith. B. D.

† All Hindu astronomers suppose that every planet daily traverses 12000 YOJANAS nearly in its orbit and as the part of a planet's orbit intercepted between the sensible and rational horizon is equal to the earth's semi-diameter (or 800 YOJANAS which $= \frac{1}{15}$ th of 12000) therefore, the extreme or horizontal parallax of a planet is thought to be equal to $\frac{1}{15}$ part of its diurnal motion : thus the Moon's horizontal parallax is 52′ 42″ nearly and the Sun's 3′ .. 56″ and hence the horizontal parallax of the Moon from the Sun is = (52′ .. 42″) — (3′ .. 56″) = 48′ .. 46″. And four GHAṬIKÁS in which the Moon describes 48′ .. 46″ from the Sun is the horizontal parallax in time.

Now, let

l = the latitude of a planet (the Sun or Moon),
d = the difference between the places of the planet and the nonagesimal,
a = the altitude of the nonagesimal,
p = the horizontal parallax,
x = the parallax in longitude,
y = the parallax in latitude.

Then we have the equation,

$$x = p \frac{\sin a. \sin (d + x)}{\text{R}. \cos. (l \pm y)}$$

which is common in astronomy.

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To find the accurate parallax, and the apparent time of conjunction.

9. Subtract the parallax in time (just found) from the end of the true time of conjunction if the place of the Sun be beyond that of the nonagesimal; but if it be within, add the parallax. At this applied time of conjunction find again the parallax in time and with it apply the end of the true time of conjunction and repeat the same process of calculation until you have the same parallax and the applied time of conjunction in every repetition. (The parallax lastly found is the exact parallax in time and the time of the conjunction is the middle of the solar eclipse.)

To find the Moon's parallax in latitude from the Sun.

10. Multiply the DṚIKSHEPA (or the sine of the zenith-distance of the nonagesimal) by the mean diurnal motion of the Moon from the Sun, and divide the product by fifteen times the radius: the quotient is the parallax in latitude of the Moon from the Sun.

Otherwise.

11. Dividing the DṚIKSHEPA by 70, the quotient is the same amount of parallax (found in the preceding S'LOKA) or multiplying the DṚIKSHEPA by 77 and dividing by the radius (i. e. 3438), the quotient is the same.

To find the apparent latitude of the Moon.

12. The amount of the parallax in latitude (just found) is south or north according as the nonagesimal is south or north (of the zenith). Add this amount to the Moon's latitude if they are of the same

In this, if we take for convenience's sake sin d for sin $(d + x)$ and R. for cos $(l \pm y)$ on account of the smallness of x, y and l in an eclipse, then we have

$$x = p \frac{\sin a . \sin d}{R^2}$$

Now, it is evident that if p be assumed, the horizontal parallax of the Moon from the Sun in time (or $p = 4$ GHAṬIKÁS) x will be the Moon's parallax in longitude from the Sun, and then

$$x = \frac{4 \sin a \sin d}{R^2} = \frac{\sin d}{\frac{(\frac{1}{4} R^2)}{\sin . a}} = \frac{\sin d}{\text{chheda.}}$$

B. D.

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name, but if of contrary names, subtract it. (The result is the apparent latitude of the Moon).

13. (In the solar eclipse) through the apparent latitude of the Moon (just found) find the STHITYARDHA* MARDARDHA magnitude of the eclipse &c. as mentioned before : the VALANÁ, the eclipsed portion of the disc at any assigned time &c. are found by the rule mentioned in the Chapter on the lunar eclipses.

To find the apparent STHITYARDHAS and MARDÁRDHAS in solar eclipses.

14, 15, 16 and 17. Find the parallaxes in longitude (converted into time) by repeated calculation at the beginning of the eclipse found by subtracting the first STHITYARDHA (just found) from the time of conjunction, and at the end found by adding the second STHITYARDHA. If the Sun be east of the nonagesimal and the parallax at the beginning be greater and that at the end be less than the parallax at the middle, or if the Sun be west, and the parallax at the beginning be less and that at the end be greater than the parallax at the middle, add the difference between the parallaxes at the beginning and the middle, or at the end and the middle to the first or the second STHITYARDHA (above found) : otherwise subtract the difference. It is then when the Sun is east or west of the nonagesimal at the times both of the beginning and the middle or of the middle and the end, otherwise add the sum of the parallaxes (at the time of the beginning and middle or of the end and the middle) to the first or the second STHITYARDHA (Thus you have the apparent STHITYARDHAS and from these the times of the beginning and the end of the eclipses of the Sun.)

In the same manner, find the apparent MARDÁRDHAS (and the times of the beginning and end of the total darkness in the total eclipses of the Sun).

End of the fifth Chapter.

* This STHITYARDHA is called the mean STHITYARDHA in the solar eclipse. B. D.

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CHAPTER VI.

On the Projection of Solar and Lunar Eclipses.

Object.

1. Since the phases of the lunar and solar Eclipses cannot be exactly understood without their projection, I therefore explain the excellent knowledge of the projection.

To describe the circle in which the valaná is to be marked.

2. Having marked at first a point on the floor levelled with water, describe, on the point as centre with 49 digits as radius, a circle in which the VALANÁ (as found in the fourth Chapter) is to be marked.

Other two circles concentric with the first.

3. (On the same centre,) describe a second circle named the SAMÁSA with the radius equal to half the sum of the diameters of that which is to be covered and that which is the coveror, and a third circle with the radius equal to the semi-diameter of that which is to be covered.

The directions of the beginning and end of the lunar and solar eclipses.

4. (In these circles determine the north and south, and the east and west lines* as mentioned before (in the 3rd Chapter).

In a lunar eclipse, the obscuration first begins to the east and it ends to the west, (but) in a solar one the reverse of this takes place. (Therefore in the projection of the lunar eclipse, the VALANÁ is to be marked as sine to the eastern or western side of the outer circle above described according as it is found at the beginning or end of the eclipse, but in the projection of the solar eclipse, the VALANÁ found at the beginning or the end of the eclipse is to be marked to the western or eastern side of the circle respectively.)

* It is evident that these lines will represent the circle of position, and the secondary to it passes through the body which is to be eclipsed. B. D.

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To mark the VALANÁ in the first circle.

5. In a lunar eclipse mark the VALANA (as directed in the preceding S'LOKA) to the eastern side of the outer circle from the east and west line to its north or south according as the VALANA is north or south, when it is found at the beginning of the eclipse; but when it is found at the end of the eclipse, mark it to the western side of the outer circle from the east and west line to the south or north according as the VALANA is north or south. And in a solar eclipse mark the VALANA inversely (i. e. mark it at the beginning or end of the eclipse to the western or eastern side of the outer circle respectively in the same manner as mentioned before).

To mark the latitudes found at the beginning and end of the eclipse in the second circle.

6. From the end of the VALANA (as drawn before) draw a line to the centre. From this line draw another line (perpendicular to the former and) as the sine in the circle called the SAMA'SA, equal to the Moon's latitude found at the beginning or end of the eclipse, (to the north or south of the former line according as the latitude is north or south).

To find the direction of the beginning and end of the eclipse in the disc of the body which is to be covered.

7. Again, draw a line from the end of the latitude (as drawn before) to the centre. Then the point, where the body which is to be covered begins to be obscured or quits the obscuration, is the same where the line drawn before cuts the circle representing the disc of the body which is to be covered.

To determine the directions of the latitudes of the Moon in the projections.

8 and 9. In the projection of the solar eclipse, the latitudes of the Moon are always designated by their normal name, but in the projection of the lunar one they are designated reversely.

To mark the VALANÁ at the middle of the eclipse.

And in the lunar projection to the northern or southern side of the outer circle above described, according as the latitude of the Moon

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found at the middle of the eclipse is considered north or south, mark the VALANÁ determined at the middle of the eclipse from the north and south line to its east, when the VALANÁ and the latitude are of the same name; but when they are of different names, mark the VALANÁ to the west of the north and south line. And in the solar projection the reverse of this takes place.

To find the magnitude of the eclipse.

10. From the end of the VALANÁ (just marked) draw a line to the centre. On this line mark the latitude (found at the middle of the eclipse) from the centre towards (the end of) the VALANÁ.

11. With the end of the latitude (just marked) as a centre, and the radius equal to the semi-diameter of the coveror, describe a circle. The part of the third circle (as described before with the radius equal to the semi-diameter of that which is to be eclipsed) contained in the circle above described will be eclipsed.

12. In the projection (of the lunar or solar eclipse) described on the floor or board, reverse the positions of the points of the eastern and western halves of the horizon.

The limit of the magnitude of the eclipsed portion which is invisible in the solar or lunar eclipse.

13. To the 12th part of the Moon's disc the obscured portion is invisible on account of the brightness of the Moon's disc; and owing to the dazzling flash of the Sun's disc its eclipsed part when not exceeding 3 minutes, is not visible.

To find the path of the coveror.

14, 15 and 16. Call the points at the ends of the latitude (found at the beginning, middle and the end) (as marked before,) the first, the middle, and the last points respectively, describe the TIMIS between the first and middle points and the middle and the last and draw two lines through these two TIMIS; with the intersecting point of these two lines as a centre, describe such an arc as will pass through the three points. This arc will be the path of the coveror through which it will move.

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To project a given eclipsed portion.

17, 18 and 19. [When you want to project the eclipsed portion, the magnitude of which is given at the time before or after the middle of the eclipse] subtract the given portion (in digits) as found before from half the sum of the coveror and that which is to be covered. From the centre (of the three circles as described before) draw a line equal to the remainder towards the direction of the beginning or end of the eclipse according as the given time is before or after the middle, in such a manner that the end of that line may be on the path of the coveror: then with the end of that line as a centre, at the distance equal to the semi-diameter of the coveror, describe a circle: then that portion of the third circle which falls within the circle (above described) will be obscured.

To find the direction of the beginning of total darkness by the projection.

20 and 21. From the centre of the three circles, towards the direction of the beginning of the eclipse, draw a line equal to half the difference between the diameters (of the coveror and that which is to be covered) in such a manner that its end fall on the coveror's path. About the end of that line describe a circle with an extent equal to the semi-diameter of the coveror. Then you will find the direction of the beginning of total darkness where the third circle touches internally the circle above described.

To find the direction of the end of the total darkness.

22. In the same way draw the said line towards the end of the eclipse and describe a circle as above. Then you will find the direction of the end of total darkness just as mentioned before.

The colour of the eclipsed portion of the Moon.

23. When the eclipsed portion of the Moon's disc is less than the half, it appears of a smoky colour, when it is greater than the half, it appears of a black colour: and when the Moon's eclipsed portion is greater than $\frac{3}{4}$ths of the whole it appears of a dusky copper hue, and in a total eclipse it appears of a tawny hue.

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This science is very secret.

24. (O Maya) this science, secret even to the Gods, is not to be given to any body, but to the well-examined pupil who has attended one whole year.

End of the sixth Chapter.

CHAPTER VII.

On the conjunction of the planets.

Kinds of conjunction.

1. The conjunction of the five minor planets is considered their fight or association with each other (according to their light and position as will be explained afterwards): but their conjunction with the Moon, is considered their association with her and with the Sun is their ASTAMANA disappearance.

To find whether the time of coujunction is past or future.

2. The conjunction of two planets, both moving eastward, is past when the place of the quick moving planet is beyond that of the slow-moving one, otherwise (i. e. when the place of the quick-moving planet is within that of the slow-moving) their conjunction is future. But when both the planets have retrograde motions, the reverse of this takes place.

3. When, of the two planets, (only) one is moving eastward and its place is beyond that of the other (which move to the west) their conjunction is past: but when the place of the retrograde is beyond that of the other (i. e. the east-moving) the conjunction is future.

To find the time of conjunction from a given time.

(When you want to know the exact time of conjunction of two planets, find their true places at any given time near the time of conjunction:) (then) multiply the difference in minutes between

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the places (above found) by the diurnal motions of the planets in minutes (separately),

4. And divide the two products by the difference between the diurnal motions, when the motions of the planets are both direct or both retrograde; but when of the planets one is retrograde, divide the two products (above found) by the sum of the diurnal motions: (the results are the changes of the planets.)

5. From the places of these two planets (found at the given time) subtract their changes when the conjunction is past, but when it is future add the changes to the places. (This rule applies when the planets move eastward,) but when they retrograde, the reverse of this takes place. When one of the two planets is retrograde, add or subtract its change to or from its place (according as the conjunction is past or future).

6. Thus the places of the planets on the ecliptic applied with their changes become equal (to each other): divide the difference between the places of the planets (found at the given time) by the divisor which is taken before in finding their changes, the quotient will be the interval in days, GHAṬIKÁS &c. (between the given time and the time of conjunction).

7. Having found the lengths of the day and night of the places of the planets (found at the time of conjunction) and their latitudes in minutes, (determine for that time), the time* from noon (i. e. from the time when the planet's place comes to the meridian) and that from rising or setting of the place of each of the two planets with the horoscope (at that time according as the planet's place is east or west of the meridian of the place).

The correction called the ÁKSHA DRIKKARMA.

8. Multiply the latitude of the planet by the equinoctial shadow and divide the product by 12; the quantity obtained being multiplied by the time in GHAṬIKÁS from noon of the planet's place

* The time can be found by the Rule mentioned in S'LOKA 49th of the 3rd Chapter. B. D.

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and divided by half the length of the day of the planet's place (as found before), gives the correction called the ÁKSHA DṚIK-KARMA.

9. Subtract the correction from the planet's place when it is east of the meridian, and add when it is west: this holds when the latitude of the planet is north, but when it is south add the correction to the planet's place when it is east of the meridian and subtract when it is west.

The correction called the ÁYANA DṚIKKARMA.*

10. Add 3 signs to the planet's place and find the declination from the sum. Then the number of minutes contained in the planet's latitude multiplied by the number of degrees contained in the declination (above found) gives the correction in seconds (called the ÁYANA DṚIKKARMA). Add or subtract this correction (to or from the place of the planet) according as the declination (above found) and the planet's latitude are of the same name or of different names.

The use of the DṚIKKARMA in finding the conjunctions &c.

11. In finding the times of conjunctions of the stars and planets and those of rising and setting of the planets and in finding the phases of the Moon, this DṚIKKARMA correction must be applied (to the place of the planet) at first.

To find the distance of two planets in the same circle of position.

12. (Thus apply the two portions of the DṚIKKARMA correction above found, to the equal places of the two planets as found in 6th S'LOKA of this Chapter, and from these places applied, find the apparent time of conjunction by the Rule as mentioned in the S'LOKAS 2nd to 6th: and repeat the operation until you get the time at which the places of the two

* DṚIKKARMA is the correction requisite to be applied to the place of a planet, for finding the point of the ecliptic on the circle of position which passes through the planet. This correction is to be applied to the place of the planet by means of its two portions, one called the ÁYANA DṚIKKARMA and the other the ÁKSHA DṚIKKARMA. The place of a planet with the ÁYANA DṚIKKARMA applied, gives the point of the ecliptic on the hour circle which passes through the planet: and this corrected place of the planet again, with the ÁKSHA DṚIKKARMA applied, gives the point of the ecliptic on the circle of position which passes through the planet. B. D.

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planets with the two portions of the DRIKKARMA applied become equal to each other. This time is the exact apparent time of conjunction of those two planets.) Find again the places of the planets (at the time of their exact apparent time) and their latitudes from them: then find the difference between the latitudes when they are of the same name and the sum when they are of different names; the result will be the north and south distance (between those two planets at that time).

The apparent diameters of the planets in minutes.

13. The diameters of Mars, Saturn, Mercury, Jupiter and Venus reduced to the Moon's orbit are 30, 37½, 45, 52½ & 60 (yojanas respectively).

14. These diameters multiplied by 2 and the radius and divided by the sum of the radius and the hypothenuse found in the fourth operation (as mentioned in the 2nd Chapter) become their rectified diameters. Divide these rectified diameters by 15, the quotients are the minutes contained in the apparent diameters of the planets.

Observation of the planets.

15. On the levelled floor (place a gnomon &) mark the shadow (found at any assigned time from the bottom of the gnomon) to the opposite side of the planet: then show the planet in the mirror placed at the end of the shadow (just marked): the planet will be seen in the direction passing through the end of the shadow and the reflected end of the gnomon.

16. (When, at the time of conjunction of two planets, they will be above the horizon) erect two styles, five cubits long, one cubit buried in the ground, in the north and south line, at the distance equal to that of the two planets (as found in the 12th S'LOKA of this Chapter, (reduced to digits by the Rule as mentioned in S'LOKA 26th of the 4th Chapter).

17. Mark the shadows from the bottoms of the styles (as mentioned in S'LOKA 15th) and draw lines from the ends of the shadows to those of the styles: then the astronomer may show the planets in the lines (above drawn).

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18. (Thus) the planets will be seen in the heaven at the ends of the styles.

The fight and association of the planets.

In the conjunction of any two minor planets, there is their fight called the Ullekha (paring) when their discs only touch each other: but when the discs cross each other, the fight is called the Bheda (breaking).

19. When in the conjunction, the rays of the two planets mix with each other, it is their fight, called the ans'uvimarda (the mixture of the rays).

When in the conjunction of the two planets, their distance (found in s'loka 12th) is less than one degree, it is their fight called the apasavya (the contrary) if one of the two planets be smaller; (otherwise the fight is not distinct).

20. (In the conjunction) when the distance of the planets is greater than one degree, it is their association, if the discs of the planets are both large and bright; (otherwise the association is indistinct).

Which planet is conquered in the fight.

In the fight called apasavya that planet is conquered which is obscure, small and gloomy.

21. And that planet is overcome which is rough, discoloured or south (of the other).

Which is the conqueror.

And that is the conqueror of which the disc is the brighter and larger, whether it be north or south (of the other).

Kinds of fight.

22. If (in the conjunction) the planets both be very near to each other and bright, then their fight is called the samágama: If both the planets be small or overpowered, then the fight is called the Kúṭa or vigraha (respectively).

23. (In the fight of Venus with any other minor planet,) Venus is usually the conqueror whether she be north or south (of the other).

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Find the time of conjunction of the moon with any of the minor planets in the same way as mentioned before.

24. This (i. e. the association and fight of the planets) is (only) imaginary, intended to foretel the good and evil fortune people, since the planets being distant from each other move in their own (separate) orbits.

End of the Seventh Chapter called the GRAHAYUTI or the planetary conjunctions.

CHAPTER VIII.

On the conjunction of the planets with the Stars.

To find the longitudes of the principal stars of the Asterisms.

1. I declare the number of the minutes contained in the BHOGAS* of (all) the Asterisms (AS'WINÍ, BHARAṆÍ, &c. except the UTTARÁSHÁDHÁ, ABHIJIT, S'RAVAṆA and DHA-

* Dividing the number of minutes contained in the longitude of the principal star of an Asterism by 800 and dividing the remainder by 10, the quotient obtained is here called the BHOGA of the ASTERISM. B. D.

Note on V 2 to 9. For convenience' sake the longitudes of the principal stars of the four Asterisms UTTARÁSHÁDHÁ, ABHIJIT, S'RAVAṆA and DHANISHTHA only are given and the BHOGAS of the others from which the longitudes of the remaining principal stars can easily be found by the rule mentioned in 1st S'LOKA, are given.

The longitudes and latitudes of the stars mentioned here are the apparent ones. The apparent longitude of a star is the distance from the origin of the Ecliptic to the intersecting point of this circle and the circle of declination passing through the star: and the apparent latitude of a star is the sum or difference of its true declination and the declination of the intersecting point of the Ecliptic and the circle of latitude passing through the star, according as the said declinations are of different names or of the same name.

The following table will exhibit the names of the Asterisms and of their principal stars as supposed to be meant, their apparent longitudes as will be found from their BHOGAS, and their apparent latitudes.

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NISHṬHÁ). Multiply the BHOGA of each Asterism by 10 and to the product add the spaces of the antecedent Asterisms (each of which contains 800 minutes as mentioned in S'LOKA 64th of the second Chapter), the sum is the longitude (of the principal star of the asterism).

The BHOGAS of the Asterisms.

2. (The number of minutes in the BHOGA of the Asterism called A'SWINÍ is) 48, (of BHARAṈÍ) 40, (of KRITTIKÁ) 65, (of ROHIṈÍ) 57, (of MṚIGA) 58, (of ARDRÁ) 4, (of PUNARVASU) 78, (of PUSHYA) 76, and (of ÁS'LESHÁ) 14.

3. (The BHOGA, in minutes, of MAGHÁ is) 54, (of PÚRVÁ-PHÁLGUNÍ) 64, (of UTTARÁ-PHÁLGUNÍ) 50, (of HASTA) 60, (of CHITRÁ) 40, (of SWÁTÍ) 74, (of VIS'AKHÁ) 78, (and of ANURÁDHÁ) 64.

Asterisms.	YOGA-TÁRÁS *or principal stars.*	*Apparent longitudes,*			*Apparent latitudes*	
		s	°	′	°	
As'winí,	α Arietis,	0	8	0	10	N.
Bharaṇí,	Musca,	0	20	0	12	N.
Krittiká,	π Tauri, Pleiades,	1	7	30	5	N.
Rohiṇí,	α Tauri, Aldeharan,	1	19	30	5	N.
Mríga,	λ Orionis,	2	3		10	S.
Ardrá,	α Orionis,	2	7	20	9	S.
Punarvasu,	β Geminorum,	3	3		6	N.
Pushya,	δ Cancri,	3	16		0	N.
As'leshá,	α 1 and 2 Cancri,	3	19		7	S.
Maghá,	α Leonis, Regulus,	4	9		0	N.
Purvá-phálguní	δ Leonis,	4	24		12	N.
Uttará-phálguní,	β Leonis,	5	5		13	N.
Hasta,	γ or δ Corvi,	5	20		11	S.
Chitrá,	α Virginis, Spica,	6	0		2	S.
Swátí,	α Bootis; Arcturus,	6	19		37	N.
Vi'sákhá,	α or χ Libra,	7	3		1	30′ S.
Anurádhá,	δ Scorpionis,	7	14		3	S.
Jyeshṭhá,	α Scorpionis, Antares,	7	19		4	S.
Múla,	ν Scorpionis,	8	1		9	S.
Púrváshádhá,	δ Sagittarii,	8	14		5	30′ S.
Uttaráshádhá,	τ Sagittarii,	8	20		5	S.
Abhijit,	α Lyri,	8	26	40′	60	N.
S'ravaṇa,	α Aquilæ,	9	10		30	N.
Dhanishṭhá,	α Delphini,	9	20		36	N.
S'ataṭáraká,	λ Aquarii,	10	20		0	30′ S.
Púrvábhádrapadá,	α Pegasi,	10	26		24	N.
Uttarábhádrapadá,	α Andromedo,	11	3		26	N.
Revatí,	ζ Piscium,	11	29	5	0 0	N.

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4. (The BHOGA, in minutes, of JYESHṬHÁ is) 14, (of MULA) 6, and (of PÚRVÁSHÁḌHÁ) 4. The principal star of UTTARÁSHÁDHÁ is in the middle of the space of PÚRVÁSHÁḌHA (i. e. the longitude of the principal star of UTTARÁSHÁḌHA is 8 signs and 20 degrees). The principal star of ABHIJIT is at the end of the space of PÚRVÁSHÁDHA (i. e. the longitude of the principal star of ABHIJIT is 8 signs, 26 degrees and 40 minutes) and (the principal star of) S'RAVAṆA is situated at the end (of the space) of UTTARÁSHÁDHÁ (i. e. the longitude of the principal star of S'RAVAṆA is 9 signs and 10 degrees).

5. The principal star of DHANISHṬHÁ is at the junction of the third and fourth quarters of the space of S'RAVAṆA (i. e. the longitude of the principal star of DHANISHṬHÁ is 9 signs and 20 degrees). (The BHOGA, in minutes, of S'ATATÁRAKÁ is) 80 (of PÚRVÁBHÁDRAPADÁ) 36, (and of UTTARÁBHÁDRAPADÁ) 22.

6 to 9. (The BHOGA of REVATÍ is) 79.

The latitudes of the principal stars of the Asterisms As'WINÍ, &c. from the ends of their mean declinations are 10° N., 12° N., 5° N., 5° S., 10° S., 9° S., 6° N., 0°., 7° S., 0°., 12° N., 13° N., 11° S., 2° S., 37° N., 1°½ S., 3° S., 4° S., 9° S., 5°½ S., 5° S., 60° N., 30° N., 36° N., ½° S., 24° N., 26° N., and 0° respectively.

The longitudes and latitudes of the stars AGASTYA, MRIGAVYÁDHA, AGNI and BRAHMAHRIDAYA.

10, 11 and 12. The star AGASTYA (or Canopus) is at the end of the sign Gemini at a distance of 80° south (from its corresponding point in the ecliptic, i. e. the longitude of AGASTYA is 90° and its latitude is 80° S.) and the star MRÍGAVYÁDHA or the Hunter (which is evidently Sirius) is situated in the 20th degree of the sign Gemini (i. e. its longitude is 2 signs and 20 degrees) and its latitude from the end of its mean declination (from its corresponding point in the ecliptic,) to the south is 40°.

The stars called AGNI (or β Tauri) and BRAHMAHRIDAYA (or Capella) are in the 22nd degree of the sign Taurus (i. e. the

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longitude of both of them is 1 sign and 22°. The latitudes of these two stars are 8° and 30° N. respectively.

Having framed a spherical instrument examine each of the (said) apparent latitudes and longitudes.

Crossing the cart of Rohiṇí.

13. That planet will cross the cart (of the Asterism) Rohiṇí (i. e. the place of Rohiṇí which is figured as a cart) which is placed at the 17th degree of the sign Taurus and of which the south latitude is greater than 2°.

To find the conjunction of a planet with a star.

14. (When you want to know the time of conjunction of a planet with a star) find the lengths of the day and night of the star as you found those of a planet (in the preceding chapter): and apply the Áksha-drikkarma (only) to the longitude of the star as mentioned before; then proceed just in the same way as in finding them in planetary conjunctions: and find the days (past or future from the given time to that of conjunction of the planet with the star) from the diurnal motion of the planet (only).

To know whether the time of conjunction is past or future.

15. (At a given time), when the longitude of the planet (with the two portions of the Dṛikkarma applied) is less than that of the star (with the Áksha-dṛikkarma applied) the conjunction is future: and when the longitude of the planet is greater than that of the star, the conjunction is past: (this holds when the planet is direct) (but) when it is retrograde the conjunction is contrariwise (i. e. when the longitude of the planet is less or greater than that of the star the conjunction is past or future).

Yoga-tárás or principal stars of the Asterisms.

16. The north star of (each of the Asterisms) Púrváphálguni, Uttaráphálguni, Púrvá bhádrapadá, Uttará bhádrapadá Púrváshádhá, Uttaráshádhá, Visákhá, As'wini and Mríga is called its yoga-tára or the principal star.

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17. The star which is near to and west of the north-western star of the Asterism Hasta is its Yoga-tára; and the western star of the Asterism Dhanishṭha is its Yoga-tára.

18. The middle star of (each of the Asterisms) Jyeshṭhá, S'ravaṇa, Anurádhá, and Pushya is its Yoga-ṭárá: and the southern star of each of the Asterisms Bharaṇí, Kṛittiká, Maghá, and Revatí is its Yoga-tára.

19. The eastern star of each of the Asterisms Rohiṇí, Punarvasu, Múla, and As'leshá is its Yoga-tárá and of the remaining Asterisms that is the Yoga-tárá which is the brightest (in each Asterism).

The longitude and latitude of the star Prajápati.

20. The star Prajápati (Aurigæ) is 5 degrees to the east of the star Bhrahma-hṛidaya. Its longitude is 1 sign and 27° and the latitude is 38° N.

Of the stars Apám-vatsa and Ápa.

21. The star Apám-vatsa (b 1. 2. 3) is situated in the Asterism Chitrá five degrees north (of its principal star) (i. e. the longitude of Apámvatsa is equal to that of the principal star of Chitrá or 180°: and its latitude is 3° N.). (And in the same Asterism) the star Ápa (Virginis), somewhat larger than Apám-vatsa, is north of it at a distance of 6° (i. e. the longitude of Ápa is 180° and the latitude 9° N.)

End of the eighth Chapter on the conjunction of the planets with the stars.

CHAPTER IX.

On the heliacal rising and setting of the planets and stars.

1. I now explain the heliacal rising and setting of the bodies (the moon and other planets and stars) which have little light and (consequently) disappear on account of the brilliancy of the sun (when he approaches them).

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The planets which set heliacally in the western horizon and rise heliacally in the eastern horizon.

2. Jupiter, Mars and Saturn set heliacally in the western horizon when their places are beyond that of the sun: and they rise heliacally in the eastern horizon when their places are within that of the sun: and the same thing takes place with respect to Venus and Mercury when they have retrograde motion.

The planets which rise in the eastern horizon and set in the western horizon.

3. The moon, whose motion is quicker than that of the sun, and Mercury and Venus when they have quicker motion, set heliacally in the eastern horizon when their places are within the place of the sun: and rise heliacally in the western horizon when their places are beyond it.

To find the time at which a planet rises or sets heliacally.

4. (When you want to determine the time of the heliacal rising or setting of a planet), find (at any given day near to that time) the true places of the sun and the planet at the sun's setting, when the planet's heliacal rising or setting is in the western horizon; (but) when it is in the eastern horizon, determine the places at the rising of the sun: then apply the DṚIKKARMA correction to the planet's place (as mentioned in the seventh Chapter).

5. (When the planet's heliacal rising or setting is in the eastern horizon) find the time in PRÁṆAS, from the places (just found) of the sun and the planet (by the rule mentioned in S'LOKA 49th Chapter III.): (It will be the time from the planet's rising to the rising of the sun). But when the heliacal rising or setting of the planet is in the western horizon, find the time, in PRÁṆAS, from the places of the sun and the planet with 6 signs added: (It will be the time from the setting of the planet to that of the sun). The time, in PRÁṆAS, (thus found) divided by 60 gives the KÁLÁNS'AS, the degrees of time (i. e. the time turned into degrees at the given rising or setting of the sun.)

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6. (The degrees of time at which before the sun's rising or after the sun's setting a heavenly body rises or sets heliacally, are called the KÁLÁNS'AS of that body). Thus the KALÁNS'AS of Jupiter are 11, of Saturn 15 and of Mars 17. (i. e. when the degrees of time found by the rule mentioned in S'LOKA 5th are 11, 15 or 17 of Jupiter, Saturn or Mars respectively, the planet will rise or set heliacally).

7. Venus sets heliacally in the western horizon and rises in the eastern horizon by its 8 degrees (of time) on account of the greatness of its disc (when it has retrograde motion, but when it has direct motion) and hence its disc becomes small, it sets heliacally in the eastern horizon and rises in the western horizon by 10 degrees (of time).

8. Thus Mercury rises or sets heliacally at the distance of 12 degrees of time from the sun, when it becomes retrograde; but when it is moving quick it rises or sets heliacally at the distance of 14 degrees.

9. When (at a given time) the KÁLÁNS'AS (found from the places of the planets by the rule mentioned in 5th S'LOKA) are greater than the planet's own KALÁNS'AS (just mentioned), the planets become visible; (but) when less, the planets having their discs involved in the rays of the sun, become invisible on the earth.

10. Find the difference, in minutes, between the KALÁNS'AS (i. e. KALÁNS'AS found from the place of the planet at the given time, and those which are the planet's own as mentioned before): and divide it by the difference between the diurnal motions* of the sun and the planet; the quantity obtained is the interval in days, (ghaṭikás) &c., between the given time and that of the planet's heliacal rising or setting. (This holds when the planet is direct; but) when it is retrograde, take the sum of the diurnal motions of the sun and the planet for the difference of the diurnal motions.

* Here motions should first be turned into time (as directed in S'LOKA 1 1th to make the dividend and divisor similar. B. D.

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11. The diurnal motions of the sun and the planet multiplied by the numbers of PRÁṆAS contained in the rising periods of the signs occupied by the sun and the planet, and divided by 1,800, become the motions in time. From these motions (turned into time) find the time past or future in days, GHAṬIKÁS &c., from the given time to the time of heliacal rising or setting of the planet.

12. The stars SWÁTÍ (Arcturus), AGASTYA (Canopus) MṚIGAVYÁDHA (Sirius), CHITRÁ (Spica), JYESHṬHÁ (Antares), PUNARVASU (β Geminorum), Abhijit (α Lyræ) and BRAHMAHRÍDAYA (Capella) rise or set heliacally by 13 degrees of time.

13. The stars HASTA (δ Corvi), S'RAVAṆA (α Aquilæ) PÚRVAPHÁLGUNÍ (δ Leonis), UTTARÁ-PHÁLGUNÍ (β Leonis), DHANISHTHÁ (α Delphini), ROHIṆÍ (α Tauri), MAGHÁ (Regulus), VIS'ÁKHÁ (α Libræ) and AS'WINÍ (α Arietis) rise (or set) heliacally by 14 degrees of time.

14. The stars KṚITTIKÁ (π Tauri, Pleiades), ANURADHÁ (δ Scorpionis), MÚLA (ν Scorpionis), AS'LESHÁ (α 1 and 2 Cancri), ÁRDRÁ (α Orionis) PÚRVÁSHÁDHÁ (δ Sagittarii) and UTTARÁSHAḌHÁ (τ Sagellarii) rise (or set) by 15 degrees of time.

15. The stars BHARAṆÍ (Musca), PUSHYA (δ Cancri) and MṚIGA (λ Orionis), on account of their smallness, rise or set heliacally by 21 degrees of time: and the others [i. e. S'ATATÁRAKÁ (λ Aquarii), PÚRVÁ-BHÁDRAPADÁ (α Pegasi), UTTARÁ-BHÁDRAPADA (α Andromedæ), REVATI (ζ Piscium), AGNI (β Tauri), PRAJÁPATI (δ Aurigæ), APÁMVATSA (b 1. 2. 3.) and ÁPA (δ Virginis)] rise and set by 17 degrees of time.

16. The KÁLÁNS'AS (of a planet and those which are found at a given time from the place of the planet) multiplied by 1,800 and divided by the rising period of the sign which is occupied by the planet, give the degrees of the ecliptic. (Then in S'LOKA 10th) take the degrees of the ecliptic for their corresponding degrees of time and from them find the time of heliacal rising or setting of the planet.

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17. The said stars rise heliacally in the eastern horizon and set heliacally in the western. Apply the AKSHA-DṚIKKARMA to their longitudes and (through them) find the days past or future from the given time to the time of heliacal rising or setting of the stars from the diurnal motion of the sun only (by the rule mentioned in 10th S'LOKA).

18. The stars ABHIJIT (*a* Lyræ), BRAHMA-HṚIDAYA (Capella), SWÁTÍ (Arcturus), S'RAVAṆA (*a* Aquilæ), DHANISHṬHÁ (*a* Delphini) and UTTARÁ-BHÁDRAPADÁ (*a* Andromedæ) never disappear owing to the sun's light on account of the greatness of their north latitudes (i. e. these stars having great north latitudes never set heliacally) in the northern hemisphere.

End of the ninth Chapter on the heliacal rising and setting of the planets and stars.

CHAPTER X.

On the phases of the Moon and the position of the Moon's cusps.

1. Find the time also at which the Moon will rise or set heliacally in the same way as mentioned before. She becomes visible in the western horizon and invisible in the eastern horizon by 12 degrees of time.

To find the time of daily setting of the Moon.

2. Find the true places of the Sun and the Moon (at Sun-set of that day of the light half of a lunar month at which you want to know the time of daily setting of the Moon) and apply the two portions of the DṚIKKARMA to the moon's place); from those places, with 6 signs added, find the time in PRÁṆAS (just in the same way) as mentioned before (in 5th S'LOKA of the preceding Chapter). At these PRÁṆAS after the sun-set, the Moon will set (on that day).

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To find the time of daily rising of the Moon.

3. (But when you want to know the time of the Moon's daily rising on a day of the dark half of a lunar month) find the true places of the Sun and the Moon (at sun-set) and add 6 signs to the Sun's place (and apply the two portions of the DṚIKKARMA to the Moon's place); from these places (i. e. from the Sun's place with 6 signs added and from the Moon's place with the DṚIKKARMA applied) find the time in PRÁṆAS (in the same way as mentioned before in 5th S'LOKA of the preceding Chapter). At this time in PRÁṆAS after sun-set the Moon will rise (on that day).

To find the phases of the Moon.

4. (When you want to know the phase of the moon on a day of the first quarter of a lunar month, find the true declinations of the Sun and the Moon at sun-set or sun-rise of that day) find the difference of the sines of the declinations (just found), when they are of the same name, otherwise find the sum: to this result (the difference or the sum) give the name of the same direction south or north at which the Moon is from the Sun.

5. Multiply the result by the hypothenuse of the gnomonic shadow of the Moon (at the same time as can be found by the rule mentioned in the third Chapter): find the difference between the product and twelve times the equinoctial shadow if the result be north (but) if it be south find the sum of them.

6. The amount (thus found) divided by the sine of co-latitude of the place, gives the BÁHU or base (of a right angled triangle): this is of the same name of which the amount is: and the sine of the altitude of the Moon is the KOṬI (or perpendicular of the triangle). The square-root of the sum of the squares of the BÁHU and KOṬI is the hypothenuse (of the triangle).

7. Subtract the Sun's place from that of the Moon. The minutes contained in the remainder divided by 900 give the illuminated part of the Moon: This part multiplied by the

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Moon's disc (in minutes) and divided by 12 becomes the SPHUṬA or rectified illuminated part.

8. (On a board or levelled floor) having marked a point representing the Sun, draw from that point a line equal to the BÁHU (above found) in the same direction in which the BÁHU is, and from the end of the BÁHU a line (perpendicular to it) equal to the KOṬI (as above found) to the west, and draw the hypothenuse between the end of the KOṬI and the point (denoting the Sun).

9. About the point where the KOṬI and the hypothenuse meet, describe the disc of the Moon (found at the given time). In this disc suppose the directions (east, west &c.,) through the line of the hypothenuse (i. e. in the disc suppose the east where the line of the hypothenuse cuts the disc, the west where the same line produced intersects it, and the north and south where a line passing through the centre of the disc and being perpendicular to the line of the hypothenuse cuts the disc).

10. Take a part of the hypothenuse within the disc from the (latter) intersection of the disc and the hypothenuse equal to the (rectified) illuminated part: and between the end of that part and the north and south points of the disc describe two TIMIS.

11. From the intersecting point of the two lines, drawn through the TIMIS, describe the arc which will pass through the three points (the end of the illuminated part and the north and south points of the disc). The disc thus cut by the arc will represent the form of the Moon as it will be seen on the evening of the given day.

12. Marking the directions in the disc through the KOṬI (above drawn), show the horn elevated at the end of the transverse line; this figure will represent the phase of the Moon.

13. In the dark half of the lunar month subtract the place of the Sun with 6 signs added to it, from the Moon's place, and from the remainder find the dark part of the Moon (in the same way as you found the illuminated part in the 7th S'LOKA):

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(and in the diagram) change the direction of the BÁHU and show the dark portion of the Moon in the west.

End of the tenth Chapter called S'ringonnatí which treats of the phases of the moon.

CHAPTER XI.

Called PÁTÁDHIKÁRA *which treats of the Rules for finding the time at which the declinations of the Sun and Moon become equal.*

VAIDHRÍTA.

1. It is called VAIDHRÍTA when the Sun and Moon are in the same AYANA (i. e. when they are both in the ascending or descending signs), the sum of their longitudes equal to 12 signs (nearly) and their declinations equal.

VYÁTÍPÁTA.

2. It is called VYÁTIPÁTA when the Moon and the Sun are in different AYANAS, the sum of their longitudes equal to 6 signs (nearly) and their declinations equal.

3. The Fire (named PÁTA) which arises from the mixture of the rays of the sun and the moon in equal quantities, being burnt by the air called PRAVAHA produces evil to mankind.

4. Since the (said) PÁTA frequently destroys people at the time (when the declinations of the Sun and Moon become equal) it is called VYÁTÍPÁTA. It is also called VAIDHRÍTA.

5. This PÁTA is of black colour and hard body, red eyed and gorbellied, destroyer of all people and horrible: it happens frequently.

To find time at which the true declinations of the Sun and Moon become equal.

6. When the sum of the places of the Sun and Moon, applied with the degrees of the precession of the equinoxes as found by observation, is 12 or 6 signs find their declinations.

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7. Now, if the Moon's mean declination (i. e. the declination of her corresponding point in the ecliptic) with her latitude applied (i. e. her true declination) be greater than that of the Sun, when the Moon is in an odd (1st or 3rd) quarter of the ecliptic, the PÁTA (or the instant when the declinations of the Sun and Moon become equal) is past.

8. And (if the Moon's declination be) less, (the PÁTA is future. But when the place of the Moon is in an even i. e. 2nd or 4th) quarter (of the ecliptic) the reverse of this takes place (i. e. if the Moon's true declination be greater than that of the Sun the PÁTA is future, and if less the PÁTA is past).

When the Moon's (mean) declination is subtracted from her latitude (for her true declination change the name of the Moon's quarter.

9. Multiply the sines of the declinations (as found in the 6th S'LOKA) by the radius and divide the products by the sine of the greatest declination (i. e. 24°) : take the arcs whose sines are equal to the quotients, and add the difference or half the difference of the arcs to the Moon's place when the PÁTA is future. (This result which is just applied to the Moon's place is called the moon's change).

10. But when the PÁTA is past, subtract the Moon's change from her place. The Moon's change multiplied by the true daily motion of the Sun and divided by that of the Moon gives the Sun's change: apply it to the Sun's place as in the case of the Moon.

11. Find the change of the Moon's ascending node in the same way (i. e. multiply the Moon's change by the daily motion of the node and divide the product by the Moon's true daily motion) : apply this change inversely to the node's place. Find the declinations of the Sun and the Moon again (from their places with their changes applied) and apply the same process (mentioned in the preceding S'LOKAS) repeatedly until you get their declinations equal.

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To find when a PÁTA is past or to be past.

12. The PÁTA is that instant at which the declinations (of the Sun and the Moon) become equal. Now, according as the Moon's true place found at the PÁTA by applying the Moon's change (as mentioned before) is less or greater than that found at mid-night (of that day), the PÁTA is before or after (the mid-night.)

To find the true time of the PÁTA.

13. The difference, in minutes, between the Moon's true places found at the PÁTA and the mid-night, multiplied by 60 and divided by the true daily motion of the Moon gives the GHAṬIKÁS between the PÁTA and the mid-night. (Then you will get the time of the PÁTA by adding or subtracting the GHAṬIKÁS, just found, to or from the mid-night according as the PÁTA is past or future).

To find half the duration of the PÁTAKÁLA.

14. (Find the semi-diameters, in minutes, of the Sun and the Moon by the Rule mentioned in the 4th Chapter.) The sum of the semi-diameters of the Sun and the Moon multiplied by 60 and divided by the Moon's true daily motion from the Sun gives half the duration of the PÁTA-KÁLA.*

To find the beginning, middle and end of the PÁTA.

15. The true time of the PÁTA (found in the 13th S'LOKA) is called the middle of the PÁTA: This time diminished by half the duration of the PÁTA, just found, gives the beginning of the PÁTA and increased by half the duration gives the end of the PÁTA.

16. The interval between the beginning and end of a PÁTA is horrible; being in the form of burning fire, all rites are prohibited during its continuance.

Form of the PÁTA-KÁLA.

17. As long as the distance of any point of the sun's disc (from the equinoctial) is equal to that of any point of the Moon's disc, the

* The PA'TA-KA'LA, or duration of the PA'TA, is the time during which the declination of any point of the Sun's disc and that of any point in the Moon's are equal.—B. D.

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PÁTA-KÁLA lasts and destroys the (happy results of) all rites (performed during that time).

18. People get very great religious merits from such (virtuous) acts as bathing, alms-giving, prayers, funeral ceremonies, religious obligations, burnt offerings, &c. (performed in the PÁTA-KÁLA), as well as from the knowledge of that time.

19. When the (mean) declinations of the Sun and the Moon become equal, near the equinoctial points, the PÁTA of the two kinds (i. e. VYATÍPÁTA and VAIDHRÍTA) happens twice: contrariwise (i. e. when the mean declinations become equal near the solstitial points, and the true declination of the Moon is less than that of the Sun) no PÁTA happens.

Third PÁTA.

20. There becomes a third PÁTA called (also) VYATÍPÁTA* when the minutes, contained in the sum of the places of the Moon and the Sun, divided by the BHABHOGA (or 800) give a quotient which terminates in 17 (i. e. which is more than 16 and less than 17).

GANḌÁNTA and BHASANDHI.

21. The last quarters of the NAKSHATRAS† AS'LESHÁ, JYESHTHÁ and REVATÍ are called the BHASANDHI (or junctions of NAKSHATRAS) and the first quarter of each of their following ones (i. e. MAGHÁ, MÚLA and AS'WINÍ) is called the GANḌÁNTA.

22. During the three frightful VYATÍPÁS, GANḌÁNTAS and BHASANDHÍS (just mentioned), all (joyful) acts are prohibited.

23. (O Maya,) thus far have I told you the excellent, virtuous, useful secret and great knowledge of Astronomy, what more do you want to hear?

End of the 11th Chapter called PÁTÁDHIKÁRA.

End of the First Part of the SÚRYA-SIDDHÁNTA.

* This is the YOGA or the period of time in which the sum of the places of the Sun and the Moon increases by 800′. This YOGA is the 17th reckoned from VISHKAMBHA. See 65th S'LOKA of the second CHAPTER.—B. D.

† These are the periods 9th, 18th and 27th from AS'WINÍ: they are found from the Moon's place by the Rule mentioned in the 64th S'LOKA of the 2nd CHAPTER.—B. D.

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CHAPTER XII.

On Cosmographical Matters.

1. Now, Maya-asura joining the palms of his hands, saluted (his teacher) the man who partakes of the Sun's nature, and worshipping him with his best respects asked this :—

Question about the Earth. 2. (Tell me, O my) omnipotent (master,) What is the magnitude of the Earth? what is its form? what supports it? how is it divided? and how are the seven Pátála-bhúmis or lower regions situated in it?

Question about the sun's revolution. 3. How does the Sun cause day and night? How does he, enlightening (all) the worlds, circumvolve the Earth?

Other questions. 4. Why are the day and night of of the (Gods) and Asuras mutually the reverse of each other (i. e. why is it day to the Gods when it is night to the Asuras and vice versâ) : and how is it that the (said) day and night is equal to the time in which the Sun completes one revolution?

5. By what reason does the day and night of the Pitṛis consists of a lunar month and that of man consists of 60 ghaṭikás? why are not the day and night of the same length everywhere?

6. Why are not the rulers of the days, years, months and hours in the same order? how does the starry sphere with the planets revolve, and what is its support?

7. At what distances from the Earth are the orbits of the planets and stars arranged one above the other? what are the distances (between the consecutive) orbits? what are their dimensions? and in what order are they situated?

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8. (Why is it that) the Sun's rays are vehement in summer and not so in winter: How far do the Sun's rays reach? How many MÁNAS (i. e. kinds of time as solar, lunar &c.) are there, and what their use?

9. O you omnipotent, who are acquainted with the past, (present and future events) remove my doubts (by answering my questions): (as) no one except you is omniscient and remover (of doubts).

10. Having heard the speech thus addressed by MAYA with his best respects, the man (who partakes of the Sun's nature) related to him the secret Second Part of the work.

11. O Maya, hear attentively the secret knowledge called ADHYÁTMAN (or means of apprehension) which shall tell you: I have nothing which is not to be given to those who are exceedingly attached to me.

The secret knowledge called ADHYÁTMAṆ.

12. The Supreme Being is called VÁSUDEVA. The excellent soul (PURUSHA) partaking of the nature of VÁSUDEVA is imperceptible, void of all properties, calm, the spirit or life of the universe and imperishable.

13. (This) all-pervading PURUSHA called God SANKARSHAṆA entering nature made the water and put his influence in it.

14. This (water with that influence) became a golden egg involved in darkness: In this egg the eternal ANIRUDDHA first became manifest.

15. This omnipotent ANIRUDDHA is called HIRAṆYA-GARBHA in the VEDAS (by reason of his situation in the golden egg): He is called ÁDITYA from his first appearance and (also) SÚRYA on account of the production (of the universe from him).

16. This ANIRUDDHA named SÚRYA and (also) SAVITÁ is excellent light for the destruction of darkness. This maker of the three states (UTPATTI birth or production, STHITI life or existence, and SANHÁRA death or destruction) of animate (and inanimate) things, illuminating the world (in the golden egg),—

17. This self light ANIRUDDHA destroyer of darkness is

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denominated MAHÁN (intelligence): The ṚIG-VEDA is his disc, SÁMA-VEDA his rays, and YAJUR-VEDA his body.

18. This omnipotent ANIRUDDHA consisting of the three VEDAS is time itself, cause of time, all-pervading, universal spirit, omnivagous and supreme soul and the whole universe depends on him.

19. Riding on the car of the universe to which are attached the wheel of the year and the horses of the seven metres, this ANIRUDDHA revolves at all times.

20. Three-fourths of ANIRUDDHA are hid in the heavens and one (fourth) is this manifest universe. That able ANIRUDDHA generated BRAHMÁ consciousness (AHANKÁRA) for the creation of the universe.

21. Now having bestowed the excellent VEDAS on BRAHMÁ the grandfather of all people and placed him in the middle of the golden egg, ANIRUDDHA himself revolves and illuminates the universe.

22. Then BRAHMÁ bearing the form of consciousness thought of creation. The Moon sprung from (his) mind, and the Sun, a treasure of lights, from (his) eyes.

23. From BRAHMÁ's mind sprung ether, from ether air, (from air) fire, (from fire) water, (and from water) earth successively. Thus the five primary elements were produced by the superposition of quality.*

24. The Sun and Moon are respectively of the nature of fire and water, and the five (minor planets) Mars and others (i. e. Mars, Mercury, Jupiter, Venus, and Saturn) sprung severally from fire, earth, ether, water, and air.

25. Again BRAHMÁ, of subdued passions, divided a circle, invented by himself, into 12 parts, naming it the RAS'I-VRITTA, and the same circle into 27 parts naming it the NAKSHATRA-VRITTA.

* Having produced ether with the quality of sound, air was formed by adding to ether the quality of touch; fire by adding to air the quality of form, water by adding to fire the quality of taste, and earth by adding to water the quality of smell.—B. D.

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26. Now having created things of different natures by compounding in various proportions the best, middling, and worst qualities (i. e. principles of truth, passion, and darkness) Brahmá made the universe containing Gods and animate and inanimate things.

27 and 28. Having created (Gods and animate and inanimate things) successively according to their qualities and actions, the able Brahmá arranged the planets, asterisms, stars, the earth, worlds, Gods, Demons, men, and Siddhas, regularly at proper places and times in the way mentioned in the Vedas.

29. This Brahmáṇḍa (the golden egg sacred to Brahmá) is hollow: in this (the worlds) Bhúr, Bhuvar &c., are situated. It is like a sampuṭa (a casket) formed by two kaṭáhas (frying vessels joined mouth to mouth) and of a spherical shape.

Order of the orbits of the stars and planets situated one below the other.

30 and 31. The circumference of the middle of the Brahmáṇḍa is called Vyomakakshá (the orbit of heaven). In it (i. e. Brahmáṇḍa) all the stars revolve. Beneath them Saturn, Jupiter, Mars, the Sun, Venus, Mercury and the Moon revolve one below the other, beneath them the Siddha, the Vidyádhara and clouds are situated.

Answers to the questions stated in 2nd S'loka.

32. The terrestrial globe, possessing Brahmá's most excellent power of steadiness, remains in space at the centre of the Brahmáṇḍa (which is) all around.

33. The seven Pátála Bhúmis or infernal regions formed by the concave strata of the earth are very beautiful, being inhabited by Nágas (serpents) and Asuras (demons) and having the liquors of the divine plants (which shine by their own light).

The position of Meru.

34. The golden mountain Meru, containing heaps of various precious stones, passes through the middle of the terrestrial globe (as an axis projecting on both sides at the poles).

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The inhabitants of the ends of the MERU i. e. of the two poles.

35. The Gods with INDṚA and the great holy sages inhabit the top of the MERU (i. e. the north pole) while the ASURAS are at the bottom (i. e. the south pole). They (i. e. the Gods and ASURAS) hate each other.

Situation of the great Ocean.

36. The great Ocean (the Ocean of salt water) encircles the MERU; it is like a girdle (or Zone) to the earth and separates the regions of the Gods and the ASURAS (i. e. it is at the Equator and divides the terrestrial globe into two hemispheres: the north is sacred to the Gods and the south to the ASURAS).

The four cities placed at the Equator.

37. Around the middle of the MERU in the directions of the east &c. and at equal distances in the ocean are the four cities made by the Gods in the different DWÍPAS.

38. To the east of the MERU (i. e. north pole) at a fourth part of the Earth's circumference in the BHADRÁS'WA VARSHA (a division of a continent) is the city called YAMA-KOṬI having golden ramparts and arched gateways.

39. So to the south in the BHÁRATA-VARSHA there is the great city called LANKÁ: to the west in the KETUMÁLA-VARSHA there is the city called ROMAKA.

40. To the north in the KURU-VARSHA there is the city called SÍDDHA-PURÍ (or SIDDHA-PURA). Liberal and devout men being free from pain inhabit that (city).

41. These (four cities) are situated at a distance equal to the fourth part of the Earth's circumference from each other: (and) the MERU sacred to the Gods is north of them at the same distance.

There is no equinoctial shadow at the equator.

42. When the Sun is at the equinoctial, he passes through the zenith of these (cities) and therefore, there is neither equinoctial shadow nor elevation of the terrestrial axis at these cities.

The position of the polar stars.

43. On both sides of the MERU (i. e. the north and south poles of the

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Earth) the two polar stars are situated in the heaven at their zenith. These two stars are in the horizon of the cities situated on the equinoctial regions.

44. Since the polar stars are in the horizon of the (said) cities, there is no elevation of the terrestrial axis (but) the co-latitude is 90°; so the latitude at the MERU is 90°.

The beginning of the day to the Gods and ASURAS.

45. When the Sun is above the regions of the Gods* (i. e. the northern hemisphere) he first appears to the Gods at the first point of Aries: but to the ASURAS (he first appears) at the first point of Libra, when the sun is going above the regions of the ASURAS (i. e. the southern hemisphere).

Answer to the question in 8th S'loka.

46. Owing to this (the Sun's going northward and southward) the Sun's rays are vehement in summer in the Gods' regions and in winter in the ASURAS'. Conversely they are weak (in summer in the ASURAS' regions and in winter in the Gods').

47. The Gods and ASURAS behold the Sun in the horizon at the equinoxes. The two periods in which the Sun is in the northern and southern hemispheres are mutually the day and night to the Gods and ASURAS (i. e. when the Sun is in the northern hemisphere it is day to the Gods and night to the ASURAS, and vice versâ).

48. The Sun at the first point of Aries, risen to the inhabitant of the MERU (i. e. to the Gods) and passing the three following signs (i. e. Aries, Taurus and Gemini), completes the first half of the day (of the Gods).

49. So he (the Sun) passing (the three signs) Cancer and others completes the second half of the day. In the same manner (the Sun passing) the three signs Libra, &c. and other three Capricorn, &c. (completes the first and second halves of the day of the ASURAS).

Answer to the questions in the 4th S'LOKA.

50. Therefore their day and night are mutually reverse, and the length of

* See the 36th S'LOKA of this Chapter. B. D.

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their Nycthemeron arises from the completion of the Sun's (one) revolution.

51. Their mid-day and mid-night (happen) at the time of the solstices reversely (i. e. it is mid-day to the Gods when it is the mid-night to the ASURAS, and vice versâ): The Gods and the ASURAS consider themselves each above the other.

52. The others likewise who are situated diametrically opposed (at the earth's surface) as the inhabitants of the BHADRÁSWA and KETUMÁLA (i. e. of YAMAKOṬI and ROMAKA) and those of LANKÁ and SIDDHAPURA consider (themselves) one below the other.

53. Thus everywhere on (the surface of) the terrestrial globe, people suppose their own place higher (than that of others): because this globe is in space where there is no above and below.

54. All people around their own place behold the Earth, though globular, of the form of a circular plain, on account of the smallness of their bodies.

Parallel and Right spheres.

55. This starry sphere revolves horizontally (from right) to left to the Gods and (from left) to right to the ASURAS: But at the equator (it) always (revolves) vertically (from east) to west.

56. At the equator, therefore, (the length of) the day is always of 30 GHAṬIKÁS and the length of the night is also the same: and at the regions of the Gods and those of the ASURAS (i. e. at the northern and the southern hemisphere) the day and night (except at the equinoxes) always increase and decrease reversely (i. e. at the northern regions the day increases and the night decreases, while at the southern ones the day decreases and the night increases, and vice versâ).

57. When the Sun is in the (northern) signs Aries &c. the increase of the length of the day and the decrease of the length of the night become more and more (until the Sun arrives at the tropic of Cancer and then they become less and less) at the regions of the Gods: but at those of the ASURAS the reverse of this takes place.

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58. (But) when the Sun is in the (southern) signs Libra &c. the decrease and increase both of the day and night are the reverse. The knowledge of this (increase or decrease) at every day from (the equinoctial shadow of) the given place and the Sun's declination is described before (in the 61st S'LOKA of the 2nd Chapter).

59. Multiply the Earth's circumference by the number of degrees of the Sun's declination (of a given day) and divide the product by 360° (and take the quotient). The Sun (at that day) passes through the zenith (of the place, north or south of the Equator according as the declination is north or south) at a distance in YOJANAS equal to the quotient (above found) from the equator.

Determination of the place where the day or night becomes of 60 GHAṬIKÁS.

60 and 61. In the same manner find the number of YOJANAS from the Sun's greatest declination and subtract the number from the fourth part of the Earth's circumference (and take the remainder). Then (when the Sun is) at a solstice, the day or night becomes of 60 GHAṬIKÁ'S once (in a year) at the distance in YOJANAS equal to the remainder (above found) from the equator (i. e. at the polar circles) in the regions of the Gods and the ASURAS reversely (i. e. when the Sun is at his greatest distance from the equinoctial, the day becomes of 60 GHAṬIKÁ'S at the polar circle in the northern hemisphere, while the night becomes of the same length at the polar circle in the southern one, and vice versâ).

62. (At places) between them (i. e. the equator and a polar circle on either side of the equator) the day and night increase and decrease within the 60 GHAṬIKÁ'S. Beyond that (i. e. in the polar regions) the starry sphere revolves in an opposite manner (as regards the north pole and the south).

The positions where some signs are always invisible.

63. Find the YOJANAS (as above) from the declination which arises from the sine of two signs* and subtract the YOJANAS from the fourth

* The sine of two signs (i. e. 60°) multiplied by the sine of the greatest declination and divided by the Radius gives the sine of declination. B. D.

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part of the Earth's circumference. At the distance equal to the remaining YOJANAS from the equator in the regions of the Gods, the Sun, situated at Sagittarius and Capricornus, is never seen.

64. But in the regions of the ASURAS (at the same distance from the equator), (he is never visible) when situated in Gemini and Cancer. At that quarter of the Earth's circumference in which the Earth's shadow is destroyed (i. e. never falls) the Sun will be seen.

65 and 66. From the fourth part of the Earth's circumference subtract the YOJANAS found from the declination of one sign (30°). At the distance of the remaining YOJANAS from the equator, the Sun never appears in the regions of the Gods when he is in Sagittarius, Capricornus, Scorpio and Aquarius: but in the regions of the ASURAS (at the same distance from the equator, he is never seen when situated in the four signs Taurus, &c. (i. e. Taurus, Gemini, Cancer, and Leo.).

67. The Gods at the MERU behold the Sun constantly as long as he is in (northern) six signs Aries, &c. so the ASURAS as long as he is in (the southern ones) Libra, &c.

Terrestrial tropic.

68. At the distance of the fifteenth part of the Earth's circumference (from the equator) in the regions of the Gods or the ASURAS (i. e. at the north or south terrestrial tropic) the Sun passes through the zenith when he arrives at the north or south solstitial point (respectively).

Determination of the direction of the gnomonic shadow at noon.

69. (At places) between them (i. e. between the equator and the tropics) the gnomonic shadow may be north or south at noon. Beyond this limit it falls towards the ends of the MERU (i. e. the north and south poles) in the northern and southern hemisphere (respectively).

Answer to the question in the 3rd S'LOKA.

70. The Sun when arrived at the zenith of BHADRÁS'WA (or Yamakoṭi) makes his rising in BHÁRATA (or LANKÁ), mid-night in KETUMÁLA (or RAMAKA) and setting in KURU (or SIDDAPURA).

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71. In the same manner, (the Sun) revolving from east to west, (when he reaches the zenith of BHÁRATA or LANKÁ) makes the mid-day, rising, mid-night and setting in the VARSHAS, BHÁRATA and others, i. e. BHÁRATA, KETUMÁLA, KURU and BHADRÁS'WA respectively).

Oblique sphere.

72. To one who is going to the end of the MERU (i. e. to the north or south pole from the equator) the elevation of the polar star (north or south) and the inclination of the starry sphere increase (more and more as he approaches the MERU :) and to one going towards the equator the reverse is the case with the inclination and elevation.

Answer to the question in the 2nd half of the 6th S'LOKA.

73. The starry sphere, bound at its two poles (north and south), being struck with the PRAVAHA winds revolves constantly : (so) do the orbits of the planets confined within it in regular order.

Answer to the question in 5th S'LOKA.

74. (As) on the Earth the Gods and the ASURAS behold the Sun constantly above the horizon throughout half the year, and men throughout their day, (so) do the PITRIS situated on the upper part of the Moon (behold the Sun) throughout a fortnight.

75. The orbit of the upper (of any two planets) is greater than that of the lower : and the degrees of the greater orbit (in length) are greater than those of the smaller.

76. A planet revolving in a smaller orbit passes the 12 signs in a shorter time and one going in a greater orbit (passes the 12 signs) in a longer time.

77. Therefore the Moon moving in a smaller orbit makes many revolutions while the SANAISCHARA (slow-moving i. e. Saturn) going in a greater orbit makes a few.

Answer to the question in the first half of the 6th S'LOKA.

78. Every fourth of the planets (in the order of their orbits mentioned in S'LOKA 31) reckoning from Saturn is the Ruler of a day (of the week) in succession (thus, the

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Sun, who is fourth from Saturn, is the ruler of the 1st day; the Moon, who is fourth from the Sun, is the ruler of the second day; Mars, the fourth from the Moon, is the ruler of the third day, and so on).

In the same manner every third of the planets, reckoning from Saturn (i. e. Mars, Venus, the Moon, Jupiter, &c. successively) is the ruler of a year (of 360 terrestrial days).

79. Reckoning from the Moon, the planets above her (i. e. Mercury, Venus, the Sun, &c.) are called the rulers of the months (of 30 days) successively. And from Saturn (the planets situated) one below the other (i. e. Jupiter, Mars, the Sun, &c.) are successively the rulers of the hours.*

Answer to the question in 7th S'LOKA.

80. The Sun's orbit (in YOJANAS to be stated in S'LOKA 86th) multiplied by 60 gives (the length of) the middle circle of the starry sphere. This circle of the stars of so many YOJANAS revolves above all (the planets).

81. Multiply the number of the said revolutions of the Moon in a KALPA by the Moon's orbit (to be declared in S'LOKA 85th): the product is equal to the orbit of heaven (or the circumference of the middle of the BRAHMÁNDA): to this orbit the rays of the Sun reach.

Determination of the Dimensions of the orbits of the planets and their daily motion in YOJANAS.

82. The very same (the orbit of heaven) being divided by the number of revolutions of a planet in a KALPA gives the orbit of that planet; (and dividing this orbit) by the number of terrestrial days in a KALPA, the quotient is called the daily motion (in YOJANAS) of all the planets to the east.

Of their daily motions in minutes or angular motions.

83. Multiply this number of YOJANAS of the daily motion (of all the

* v. 78 and 79. It is to be known here that the Ruler of a day (from mid-night to mid-night at LANKA) is the same as that of the first hour of the day: and the Ruler of a month or a year is the same as that of the first day of the month or year. B. D.

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planets) by the Moon's orbit and divide the product by the orbit of the planet (of which the daily motion in minutes is to be known): the quotient being divided by 15 gives the number of minutes of the motion (of that planet).

84. The orbits (of the planets) multiplied by the Earth's diameter and divided by the circumference of the Earth give the diameters of the orbits. These (diameters) diminished by the Earth's diameter and divided by 2 give the distances of the planets (from the Earth's centre).

85. The orbit of the Moon is 324,000 (YOJANAS) and that of the SIGHROCHEHA of Mercury, beyond the Moon is 1,043,209.

86. That of the SIGHROCHEHA of Venus is 2,664,637 beyond that, that of the Sun, Mercury and Venus is 4,331,500.

87. That of Mars is 8,146,909 and that of the Moon's apogee is 38,328,484.

88. That of Jupiter is 51,375,764 and that of the Moon's ascending node is 80,572,864.

89. That of Saturn is 127,668,255 and that of the fixed stars is 259,890,012.

90. The circumference of the sphere of the BRAHMÁNDEE in which the Sun's rays spread, is 18712080864000000 YOJANAS.

End of the twelth CHAPTER.

CHAPTER XIII.

On the construction of the armillary Sphere and other astronomical Instruments.

1 and 2. Now the teacher (of MAYA) being in a secret and holy place bathed, pure and adorned, and having worshipped faithfully the Sun, the planets, the asterisms and the GUHYAKAS (a kind of Demigods) explained clearly the knowledge which he had from his preceptor (the Sun) through traditional instruction, for the satisfaction of his pupil (MAYA).

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The construction of the armillary Sphere.

3 and 4. Let an astronomer make the wonderful construction of the armillary Sphere with that of the Earth (at its centre).

Having caused a wooden terrestrial globe to be made of any desired size with a staff representing the MERU passing through the (globe's) centre and projecting on both sides. (Let him fix) two circles (on the staff) called the ÁDHÁRA KAKSHÁ or the supporting circle (answering to the colures) as also the equinoctial.

The diurnal circles of the 12 signs.

5. Let three circles marked with the number of degrees in the 12 signs (or 360°) be prepared (to represent the diurnal circles at the ends of the 3 signs Aries, Taurus and Gemini) with radii answering to the respective diurnal circles in proportion to the Equinoctial.

6, 7, 8 and 9. Let him fix the three circles for Aries and other signs respectively (on the two supporting circles) marked with the degrees of declinations north and south, at the end of respective declination (north of the Equinoctial) (of the ends of the said signs). The same (circles) answer contrariwise to the (three signs) Cancer and others (at the ends of the respective declinations of the beginnings of the signs). In the same manner, let him fix (other) three circles in the southern hemisphere, for Libra and others (and) contrariwise for Capricorn and the rest. Let him also fix circles on both the supporting circles for the principal stars of the asterisms in both hemispheres as also for ABHIJIT (and Lyræ) and for the seven great saints (i. e. the seven stars composing the constellation of Ursa major), AGASTYA (Canopus). BRAHMÁ (Aurigæ) and other stars. In the very middle of all (these circles) is fixed the Equinoctial circle.

Determination of the places of the 12 signs in the sphere.

10 and 11. Let the two solstices be marked above the intersection of the Equinoctial and one of the two supporting circles (i. e. at the distance of the Sun's greatest

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declination from the intersection to the north and south on the supporting circle) and the two equinoxes (at the intersection of the equinoctial and the other supporting circle).

Then from the equinox at the exact degrees of every sign (i. e. at every 30°) the places of Aries and other signs should be determined by the transverse strings (of the circle).

The Ecliptic.

There is another circle passing from solstice to solstice.

12 and 13. (This circle) is called the Ecliptic: in this, the Sun, enlightening the worlds, always revolves.

(But) the Moon and other (planets) being attracted from the ecliptic by their nodes situated in the ecliptic are seen at the ends of (their respective) latitudes.

The Horoscope.

(The point of the ecliptic) in the eastern horizon is called the LAGNA (the horoscope) and (the point) just setting is called the ASTA LAGNA (or the setting LAGNA) on account of its setting.

The MADHYA LAGNA or the culminating point of the ecliptic.

14. The point of the ecliptic in the middle of the visible heaven (or in the meridian i. e. the culminating point of the ecliptic) as determined through the rising periods of the signs ascertained for LANKA (in 48th S'LOKA of the 3rd Chapter) is called the MADHYAMA (Lagna).

The ANTYÁ.

(Suppose a line between the two intersections of the meridian of a given place and a given diurnal circle). The string (or the portion of that line) intercepted between the meridian and the horizon (in terms of the radius of a great circle) is called ANTYÁ.

The sine of the ascensional difference.

15. And a portion (of the same line) intercepted between (the plane of) the six o'clock line and that of the horizon (in terms of the radius of a great circle) is, it is to be known, equal to the sine of the ascensional difference.

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The Horizon.

(On the terrestrial globe) considering the given place as the highest, surround the sphere with the horizon in its middle (i. e. 90° distant from the given place).

The self-revolving Spheric instrument.

16. Thus having surrounded the sphere (the axis of which should be elevated to the height of the pole) by the horizon (made as level as water) and covered (in its lower half) by wax cloth, make it rotate by the force of the current of water for the knowledge of the passage of time.

17. (Or let an astronomer) make the sphere (a self-revolving instrument) by means of mercury.

The method (of constructing the revolving instrument) is to be kept a secret, as by its diffusion here it will be known to all (and then there will be no surprise in it).

Therefore, from the instruction of the teacher construct the excellent spheric instrument (so that it may be self-revolving).

(The knowledge of) this, the Sun's method is lost at the end of every YUGA.

19. It arises again by the favour of some one (great astronomer) when he pleases.

So let other self-revolving instruments be furnished for measuring time.

20. To (such) a surprising instrument let (an astronomer) alone apply his contrivance, (in secret).

Other instruments for measuring time.

Let smart (astronomers) from the instruction of their teacher know the hour (of the day) by the dial instruments gnomon, staff, semicircle and circle in various ways.

21. Let also (astronomers) determine the hour exactly by the water-clocks, clepsydra &c., and the sand-clocks in the shape of peacock, man or monkey.

22. (For the self-revolution of the said instruments) apply the hollow spokes (half filled) with mercury, water, threads, ropes, mixture of oil and water, mercury and sand to them

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(i. e. the instruments). These applications are very difficult of attainment.

KAPALA Yantra or Clepsydra.

23. The copper vessel (in the shape of the lower half of a water jar) which has a small hole in its bottom and being placed upon clean water in a basin sinks exactly 60 times in a nyctheme-ron, is called the KAPÁLA YANTRA.

The Gnomon.

24. As also that instrument the Gnomon is very useful by day when the Sun is clear, and an excellent means of ascertaining time by taking its shadows.

Conclusion.

25. Having known exactly the science of the planets and stars and the spheric, man attains (his residence at) the spheres of the planets (Moon &c.) and becomes acquainted with the spiritual knowledge by his regeneration, attains to spiritual knowledge in a subsequent birth.

End of the thirteenth Chapter called JYAUTISHOPANISHAT.

CHAPTER XIV.

On kinds of time.

Number of kinds of time.

1. There are nine MÁNAS (kinds of time), the BRÁHMA (that of BRAHMÁ), the DIVYA (that of the Gods), the PITRYA, the PRÁJÁPATYA, as also that of Jupiter, the Solar, the Terrestrial, the Lunar and the Siderial.

The MÁNAS which are used here.

2. The four MÁNAS the solar, the lunar, the sidereal and the terrestrial are (always) in use in this world: the MÁNA of Jupiter is (used

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here) for knowing the 60 SAMVATSARAS,* and the other MÁNAS are not always (used).

Use of the solar MÁNA.

3. The lengths of the day and night, the SHAḌAS'ÍTI-MUKHAS,† the solstitial and equinoctial times, and the holy time of SANKRÁNTI (i. e. the time of the entrance of the Sun into a sign at which a good action brings good desert to the performer) are determined by the solar MÁNA.

The SHAḌAS'ÍTI MUKHA.

4. Every eighty-sixth (solar‡) day reckoned from the time of TULÁDI (i. e. from the time at which the Sun enters the sign Libra) is called SHAḌAS'ÍTI-MUKHA in succession. These four days lie (in the four solar months) when the Sun is in the four signs of two natures (i. e. Gemini, Virgo, Sagittarius and Pisces).

There are four SHAḌAS'ÍTI MUKHAS in a year.

5. (The first SHAḌAS'ÍTI-MUKHA happens when the Sun is) at the 26th degree of Sagittarius, (the second) at the 22nd degree of Pisces, (the third) at the 18th degree of Gemini and (the fourth) at 14th degree of Virgo.

6. Then (after the fourth SHAḌAS'ÍTI-MUKHA) the remaining 16 solar days of the solar month at which the Sun is in Virgo, are equal to a sacrifice (i. e. good actions performed in these days give great merit equal to that of a sacrifice) and in these days a gift given in honour of deceased ancestors is imperishable (i. e. the gift gives infinite merit).

Four common points of the ecliptic.

7. In the middle of the starry sphere, the two equinoxes are diametrically opposed, so are the two solstices (in the ecliptic); these four points (of the ecliptic) are very common.

Its other points.

8. Again, between every two consecutive points (of them) two SANKRÁN-

* See 55th S'LOKA of the first Chapter. B. D.
† This word will be explained in the following S'LOKA. B. D.
‡ By a solar day is here meant the time in which the Sun moves one degree of the Ecliptic. B. D.

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TIS or the beginnings of the signs are situated in the ecliptic: (And of the twelve points of the ecliptic, just mentioned), the points which are next to the (four common) points (i. e. the beginnings of the four signs Taurus, Leo, Scorpio and Aquarius) are called the VISHṆU-PADÍ.

Two halves of a tropical year.

9. From (the time of) the Sun's entrance into Capricorn the six solar months are the UTTARÁYAṆA (the northing of the Sun): in the same manner from the time of the entrance of the Sun into Cancer, the six solar months are the DAKSHIṆÁYANA (the southing of the Sun).

The seasons, months and year.

10. From that time (i. e. the winter solstice) the periods, in each of which the Sun remains in the two signs are the seasons S'ISIRA (the very cold season) &c.* and the twelve periods in which the Sun remains in the 12 signs Aries, &c., are the solar months and a year is equal to the aggregate of these months.

The holy time of SANKRÁNTI.

11. The number of minutes contained in the Sun's disc multiplied by 60 and divided by (his) daily motion (gives a certain number of GHAṬIKÁS.) Half these GHAṬIKÁS, before as well as after the SANKRÁNTI (or the time of the Sun's passage from one sign into another) is holy.

The lunar MÁNA.

12. The time in which the Moon, being separate from the Sun (after a conjunction), moves daily to the east is the lunar MÁNA. The time in which the Moon describes 12 degrees (from the Sun) is a lunar day.

Use of the lunar MÁNA.

13. The TITHI (lunar day), the KARAṆA (half of a TITHI), the time of marriage, shaving and all other acts, as also (the times of)

* A solar year is divided into six seasons, viz. The S'IS'IRA (the very cold season), the VASANTA (the Spring), the GRÍSHMA (the hot season) the VARSHA (the rainy season), the S'ARAT (the Autumn) and the HEMANTA (the cold season). B. D.

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religious acts of obligations, fasts and pilgrimages are regulated by the lunar MÁNA.

The MÁNA of PITṚIS.

14. A lunar month which consists of 30 lunar days, is, as mentioned before, a day and night of the PITṚIS. The end of a (lunar) month and that of the light half of that month take place in the middle of them (the day and night of the PITṚIS) respectively.

The sidereal MÁNA.

15. A daily revolution of the starry sphere is called a sidereal day.

Naming of the lunar months.

The lunar months are named from the NAKSHATRAS* (or asterisms) which take place (or in which the Moon is) on the 15th day of these months.†

16. On the 15th day of (each of the lunar months) KÁRTIKA and others, (either of every) couple of the NAKSHATRAS reckoned from KṚITTIKÁ takes place successively. (But on the 15th day of each of) the three months such as the last (i. e. ÁS'WINA) and that coming before the last (i. e. BHÁDRAPADA) and the fifth (i. e. PHÁLGUṆA) one of three NAKSHATRAS takes place.‡

Years of Jupiter.

17. (As the lunar months are named KÁRTIKA &c. from the union of their 15th day with the NAKSHATRAS KṚITTIKÁ, &c. so) the years of Jupiter are called KÁRTIKA, &c. from the union of the 15th day of the dark half of the months VAIS'ÁKHA, &c. (with the NAK-

* The NAKSHATRAS are found in the 64th S'LOKA of the 2nd Chapter. B. D.

† The first lunar month is named CHAITRA from the NAKSHATRA CHITRA, the 2nd VAIS'A'KHA', from VIS'A'KHA' the 3rd JYESHTHA, from JYESHTHA, the 4th ÁSHAḌHA from PÚRVA'S'HA'ḌHA', the 5th S'RA'VAṆA, from S'RAVAṆA, the 6th BHA'DRAPADA from PÚRVA'BHA'DRAPADA', the 7th ÁS'WINA from AS'WINÍ, the 8th KA'RTIKA from KṚITTIKA, the 9th MA'RGAS'ÍRSHA from MṚÍGAS'ÍRSHA, the 10th PAUSHA from PUSHYA, the 11th MA'GHA from MAGHA' and the 12th PHA'LGUNA from PÚRVA-PHALGUNÍ. B. D.

‡ On the 15th day of the lunar month KA'RTIKA, the NAKSHATRA KṚITTIKA or ROHIṆÍ takes place; of MARGAS'ÍRSHA, MṚÍGA or ÁRDRA', of PAUSHA, PUNARVASU or PUSHYA; of MAGHA, ÁS'LESHA or MAGHA'; of PHALGUNA, PÚRVAPHALGUNÍ or UTTARAPHALGUNÍ or HASTA; of CHAITRA', CHITRA or SWA'TI; of VAIS'AKHA, VIS'A'KHA' or ANURA'DHA'; of JYESHṬHA, JYESHṬHA' or MÚLA; of ÁSHADHA, PÚRVA'SHAḌHA' or UTTARA'SHAḌHA; of SRAVAṆA, SRAVAṆA or DHANISHṬHA; of BHA'DRAPADA, S'ATATA'RA, PÚRVA'BHA'DRAPADA' or UTTARA'BHA'DRAPADA; and of ÁS'WINA, REVATÍ AS'WINÍ or BHARAṆÍ. B. D.

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SHATRAS KRITTIKÁ, &c., when at the said 15th day) Jupiter rises or sets heliacally.

Terrestrial MÁNA.

18. The time from one rising of the Sun to the next is called a SÁVANA or a terrestrial day, from this the number of terrestrial days in a KALPA is determined: By these days the time of sacrifice is calculated.

It's use.

19. Determination of the SÚTAKA (or impurity contracted in consequence of a death or birth in one's family), the rulers of the day, month and year, and the mean motion of a planet are reckoned by SÁVANA (or the terrestrial MÁNA).

The MÁNA of the Gods.

30. It is said before that the day and night of the Gods and the ASURÁS are mutually reverse: This day and night which is found from the completion of the Sun's revolution is DIVYA (or the MÁNA of the Gods).

PRA'JA'PATYA MANA.

21. The duration of a MANU (which, as mentioned before, is equal to 71 YUGAS) is called PRÁJÁPATYA (or the MÁNA of PRAJÁPATI who was the father of MANUS). There is no division of the day and night in this MÁNA.

The BRA'HMA MANA.

The KALPA is called the BRÁHMA (or the MÁNA of BRAHMÁ).

Conclusion.

22. O superior MAYA, I declared this secret and surprisingly excellent (knowledge) to you. This (equivalent to) the holy knowledge is exceedingly meritorious and the destroyer of all sins.

23. Having known this excellent divine knowledge of the stars and the planets which is (just) imported to you, man acquires a perpetual place on the spheres of the Sun &c.

24. Having properly imparted this to MAYA and said this (the meaning of the preceding two verses) and being worshipped by him, the man who partakes of the nature of the Sun, ascended to heaven and entered the disc of the Sun.

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25. Then having learned the divine knowledge from the Sun himself, MAYA considered himself as one who had done his duty, and free from sins.

26. Then having known that MAYA had obtained a blessing of the Sun (some) saints approached and asked him respectfully the knowledge.

27. He (MAYA) being delighted gave the great knowledge of the planets to them (the saints) which is very surprising in this world, secret and equivalent to the holy knowledge.

End of the 14th Chapter, of the Second Part, and of the work.

POSTSCRIPT BY THE TRANSLATOR.

It is stated in the SÚRYA-SIDDHÁNTA that a dialogue took place between a man partaking of the nature of the Sun and a Demon called MAYA 2,164,960 years before the present time. But nobody knows who has put this dialogue into verse or the date of this versification. People believe that it is the production of some MUNI (saint), and many are of opinion that it is the oldest of eighteen ancient astronomical works. Its style is easy, and the reading of it, as of the PURÁṆAS, is considered to be meritorious. Every subject is treated more fully in this than in any other of the ancient SIDDHÁNTAS, and the revolutions of the planets are so correctly stated in it that their places can be determined with great accuracy.

The names of the eighteen ancient ṢIDDHÁNTAS are :—

1. Súrya-siddhánta.	10. Maríchi-s.
2. Brahma-s.	11. Manu-s.
3. Vyása-s.	12. Angiras-s.
4. Vasishṭha-s.	13. Lomas'a-s.
5. Atri-s.	14. Pulis'a-s.
6. Parás'ara-s.	15. Chyavana-s.
7. Kas'yapa-s.	16. Yavaṇa-s.
8. Nárada-s.	17. Bhṛigu-s.
9. Garga-s.	18. S'aunaka or Soma-s.

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Although it is generally supposed that the Súrya-siddhánta is the oldest, yet some consider the Brahma-siddhánta to be so: and it is stated in the S'ambhu-horáprakás'a (an astrological work), that the Soma-siddhánta is the first, the Brahma-siddhánta the second, and the Súrya-siddhánta the third in the order of time. But this opinion is not generally received. Of the eighteen ancient Siddhántas only four (viz. Súrya-s., Brahma-s., Soma-s., and Vasishṭha-s.) are now procurable; the others are very rare.

In the translation wherever words are supplied by way of explanation they are included in brackets. In some places the original Sanskrit is so brief and terse, that it is not only obscure, but unintelligible, without the insertion of words to complete the sense: e. g. p. 24, S'loka 64.

BÁPÚ DEVA.

Sanskrit College, Benares, 1860.

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ERRORS.

Page.	*Line from top.*	*Error.*	*Correction.*
1	7	Properties (of all created things).	Properties,
1	9	Siva.	Síva.
5	13	Reváti.	Revatí.
8	4	Kríta yuga.	Kṛita yuga.
12	32	Madhyágatí.	Madhyagatí.

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TRANSLATION

OF THE

SIDDHÁNTA ŚIROMANI.

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TRANSLATION OF THE GOLÁDHYÁYA OF THE SIDDHÁNTA-SIROMAṆI.

CHAPTER I.

In praise of the advantages of the study of the Spheric.

Salutation to GAṆESA !

Invocation. 1. Having saluted that God, who when called upon brings all undertakings to a successful issue, and also that Goddess, through whose benign favour the tongues of poets, gifted with a flow of words ever new and with elegance, sweetness and playfulness, sport in their mouths as in a place of recreation, as dancing-girls adorned with beauty disport themselves in the dance with elegance and with every variety of step, I proceed to indite this work on the Sphere. It has been freed from all error, and rendered intelligible to the lowest capacity.

Object of the work. 2. Inasmuch as no calculator can hope to acquire in the assemblage of the learned a distinguished reputation as an Astronomer, without a clear understanding of the principles upon which all the calculations of the mean and other places of the planets are founded, and to remove the doubts which may arise in his own mind, I therefore proceed to treat of the sphere, in such a manner as to make the reasons of all my calculations manifest. On inspecting the Globe they become clear and manifest as if submitted to the eye, and are as completely at command, as the wild apple (áṇwlá) held in the palm of the hand.

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Ridicule of an ignorance of the Spheric.

3. As a feast with abundance of all things but without clarified butter, and as a kingdom without a king, and an assemblage without eloquent speakers have little to recommend them; so the Astronomer who has no knowledge of the spheric, commands no consideration.

4. As a foolish impudent disputant, who ignorant of grammar (rudely) enters into the company of the learned and vainly prates, is brought to ridicule, and put to shame by the frowns and ironical remarks of even children of any smartness, so he, who is ignorant of the spheric, is exposed in an assemblage of the Astronomers, by the various questions of really accomplished Astronomers.

Object of the Armillary sphere.

5. The Armillary sphere is said, by the wise, to be a representation of the celestial sphere, for the purpose of ascertaining the proofs of the positions of the Earth, the stars, and the planets: this is a species of figure, and hence it is deemed by the wise to be an object of mathematical calculation.

In praise of mathematics.

6. It is said by ancient astronomers that the purpose of the science is judicial astrology, and this indeed depends upon the influence of the horoscope, and this on the true places of the planets: these (true places) can be found only by a perfect knowledge of the spheric. A knowledge of the spheric is not to be attained without mathematical calculation. How then can a man, ignorant of mathematics, comprehend the doctrine of the sphere &c.?

Who is likely to undertake the study with effect.

7. Mathematical calculations are of two kinds, Arithmetical and Algebraical: he who has mastered both forms, is qualified if he have previously acquired (a perfect knowledge of) the Grammar (of the Sanskrit Language,) to undertake the study of the various branches of Astronomy. Otherwise he may acquire the name (but never the substantial knowledge) of an Astronomer.

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In praise of Grammar.

8. He who has acquired a perfect knowledge of Grammar, which has been termed VEDAVADANA i. e. the mouth of the VEDAS and domicile of SARASWATI, may acquire a knowledge of every other science—nay of the VEDAS themselves. For this reason it is that none, but he who has acquired a thorough knowledge of Grammar, is qualified to undertake the study of other sciences.

The opinion of others on this work, quoted with a view of extending the study of it.

9. O learned man; if you intend to study the spheric, study the Treatise of BHÁSKARA, it is neither too concise nor idly diffuse: it contains every essential principle of the science, and is of easy comprehension; it is moreover written in an eloquent style, is made interesting with questions; it imparts to all who study it that manner of correct expression in learned assemblages, approved of by accomplished scholars.

End of Chapter I.

CHAPTER II.

Questions on the General view of the Sphere.

Questions regarding the Earth.

1. This Earth being encircled by the revolving planets, remains stationary in the heavens, within the orbits of all the revolving fixed stars; tell me by whom or by what is it supported, that it falls not downwards (in space)?

2. Tell me also, after a full examination of all the various opinions on the subject, its figure and magnitude, how its principal islands mountains and seas are situated in it?

Questions regarding those calculations used in ascertaining planets' true places and their causes.

3. Tell me, O my father, why the place of a planet found out from well calculated AHARGAṆA (or enumeration of mean terrestrial days, elapsed from

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the commencement of the KALPA)* by applying the rule of pro-

* [A KALPA is that portion of time, which intervenes between one conjunction of all the planets at the Horizon of LANKÁ (that place at the terrestrial equator, where the longitude is 76° E., reckoned from Greenwich) at the first point of Aries, and a subsequent similar conjunction. A KALPA consists of 14 MANUS and their 15 SANDHIS; each MANU lying between 2 SANDHIS. Each MANU contains 71 YUGAS; each YUGA is divided into 4 YUGÁNGHRIS viz., KRITA, TRETA', DWÁPARA and KALI, the length of each of these is as the numbers 4, 3, 2 and 1. The beginning and end of each YUGA'NGHRIS being each one 12th part of it are respectively called its SANDHYÁ and SANDHYA'NSA. The number of sidereal years contained in each YUGA'NGHRI, &c. are shewn below;

KALI, ...	432,000,
DWA'PARA, ...	864,000,
TRETA, ...	1,296,000,
KRITA, ...	1,728,000,
YUGA, ...	4,320,000,
71 × YUGA = MANU, ...	4,294,080,000,
14 MANU, ...	306,720,000,
15 MANU SANDHIS each equal to a KRITA YUGÁNGHRI,	25,920,000,
KALPA, ...	4,320,000,000,

Of the present KALPA 6 MANUS with their 7 SANDHIS, 27 YUGAS and their three YUGA'NGHRI i. e. KRITA, TRETA, and DWA'PARA, and 3179 sidereal years of the fourth YUGA'NGHRI of the 28th YUGA of the 7th MANU, that is to say, 1,972,947,179 sidereal years have elapsed from the beginning of the present KALPA to the commencement of the SA'LIWA'HANA era. Now we can easily find out the number of years that have elapsed from the beginning of the present KALPA to any time we like.

By astronomical observations the number of terrestrial and synodic lunar days in any given number of years can be ascertained and then, with the result found, their number in a KALPA or YUGA can be calculated by the rule of proportion.

By this method ancient Astronomers found out the number of lunar and terrestrial days in a KALPA as given below.

1,602,999,000,000 (synodic) lunar days } in a KALPA.
and 1,577,916,450,000 terrestrial days }

With the foregoing results and a knowledge of the number of sidereal years contained in a KALPA as well of those that have passed, we can find out the number of mean terrestrial days from the beginning of a KALPA to any given day. This number is called AHARGANA and the method of finding it is given in GAṆITÁDHYÁYA by BHA'SKARA'CHA'RYA.

By the daily mean motions of the planets, ascertained by astronomical observations, the numbers of their revolutions in a KALPA are known and are given in works on Astronomy.

To find the place of a planet by the number of its revolutions, the number of days contained in a KALPA and the AHARGAṆA to a given day, the following proportion is used.

As the terrestrial days in a KALPA,
: the number of revolutions of a planet in a KALPA
: the AHARGAṆA :
: the number of revolutions and signs &c. of the planet in the AHARGAṆA.

By leaving out the number of revolutions, contained in the result found, the remaining signs &c. indicate the place of the planet.

Now, the intention of the querist is this, why should not this be the true place of a planet? In the GAṆITÁDHYÁYA. BHÁSKARÁCHA'RYA has stated the revolutions in a KALPA, but he has here mentioned the revolutions in a YUGA on account of his constant study of the S'ISHYA-DHÍVRÍDDHIDA-TANTRA, a Treatise on Astronomy by LALLA who has stated in it the revolutions in a YUGA.—B. D.]

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portion to the revolutions in the YUGA* &c. is not a true one? (i. e. why is it only a mean and not the true place) and why the rules for finding the true places of the different planets are not of the same kind? What are the DESÁNTARA, UDAYÁNTARA, BHUJÁNTARA, and CHARA corrections?† What is the MANDOCHCHA‡ (slow or 1st Apogee) and S'ÍGHROCHCHA§ (quick or 2nd Apogee)? What is the node?

4. What is the KENDRA|| and that which arises from it (i. e. the sine, cosine, &c. of it)? What is the MANDAPHALA|| (the first equation) and S'ÍGHRAPHALA¶ (the 2nd equation) which depend on the sine of the KENDRA? Why does the place of a planet become true, when the MANDAPHALA or S'ÍGHRAPHALA

* [It may be proper to give notes explaining concisely the technical terms occurring in these questions, which have no corresponding terms in English, in order that the English Astronomer may at once apprehend these questions without waiting for the explanation of them which the Author gives in the sequel.—B. D.]

† [To find the place of a planet at the time of sun-rise at a given place, the several important corrections, i. e. the UDAYA'NTARA, BHUJA'NTARA, DES'ÁNTARA, and CHARA are to be applied to the mean place of the planet found out from the AHARGAṆA by the fact of the mean place being found from the AHARGAṆA for the time when a fictitious body, which is supposed to move uniformly in the Equinoctial, and to perform a complete revolution in the same time as the Sun, reaches the horizon of LANKA'. We now proceed to explain the corrections.

The UDAYA'NTARA and BHUJA'NTARA corrections are to be applied to the mean place of a planet found from the AHARGAṆA for finding the place of the planet at the true time when the Sun comes to the horizon of LANKA' arising from those two portions of the equation of time respectively, one due to the inclination of the ecliptic to the equinoctial and the other to the unequal motion of the Sun in the ecliptic.

The DES'A'NTARA and CHARA corrections are to be applied to the mean place of a planet applied with the UDAYA'NTARA and BHUJA'NTARA corrections, for finding the place of the planet at the time of sun rise at a given place.

The DES'A'NTARA correction due to the longitude of the place reckoned from the meridian of LANKA' and the CHARA correction to the ascentional difference. B. D.]

‡ [MANDOCHCHA is equivalent to the higher Apsis. The Sun's and Moon's MANDOCHCHAS (higher Apsides) are the same as their Apogees, while the other planets' MANDOCHCHAS are equivalent to their Aphelions. B. D.]

§ [S'I'GHROCHCHA is that point of the orbit of each of the primary planets (i. e. Mars, Mercury, Jupiter, Venus and Saturn) which is furthest from the Earth. B. D.]

|| [KENDRA is of two kinds, one called MANDA-KENDRA corresponds with the anomaly and the other called S'I'GHRA-KENDRA is equivalent to the commutation added to or subtracted from 180° as the SIGRA-KENDRA is greater or less than 180° B. D.]

¶ [MANDA-PHALA is the same as the equation of the centre of a planet and S'I'GHRA-PHALA is equivalent to the annual parallax of the superior planet; and the elongation of the inferior planets. B. D.]

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are (at one time) added to and (at another) subtracted from it? What is the twofold correction called DṚIKKARMA* which learned astronomers have applied (to the true place of a planet) at the rising and setting of the planet? Answer me all these questions plainly, if you have a thorough knowledge of the sphere.

Questions regarding the length of the day and night.

5. Tell me, O you acute astronomer, why, when the Sun is on the northern hemisphere, is the day long and the night short, and the day short and the night long when the Sun is on the southern hemisphere?

Questions regarding the length of the day and night of the Gods DAITYAS, PITṚIS and BRAHMA'.

6. How is it that the day and night of the Gods and their enemies DAITYAS correspond in length with the solar years? How is it that the night and day of the PITṚIS is equal in length to a (synodic) lunar month, and how is it that the day and night of BRAHMÁ is 2000 YUGAS† in length?

Questions regarding the periods of risings of the signs of the Zodiac.

7. Why, O Astronomer, is it that the 12 signs of the Zodiac which are all of equal length, rise in unequal times (even at the Equator,) and why are not those periods of rising the same in all countries?

Questions as to the places of the DYUJYÁ, the KUJYA', &c.

8. Shew me, O learned one, the places of the DYUJYÁ (the radius of the diurnal circle), the KUJYÁ (the sine of that part of the arc of the diurnal circle intercepted between the horizon and the six o'clock line, i. e. of the ascensional difference in terms

* [DṚIKKARMA is the correction requisite to be applied to the place of a planet, for finding the point of the ecliptic on the horizon when the planet reaches it. This correction is to be applied to the place of a planet by means of its two portions, one called the ÁYANA-DṚIKKARMA and the other the ÁKSHA-DṚIKKARMA. The place of a planet with the ÁYANA-DṚIKKARMA applied, gives the point of the ecliptic on the six o'clock line when the planet arrives at it: and this corrected place of the planet, again with the ÁKSHA-DṚIKKARMA applied, gives the point of the ecliptic on the horizon when the planet comes to it. B. D.]

† The KṚITA, TRETA', DWA'PARA and KALI are usually called YUGAS: but the four together form only one YUGA, according to the SIDDHA'NTA system, each of these four being held to be individually but a YUGA'NGHRI. L. W.

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of a small circle), and show me also the places of the declination, SAMA-SÁNKU,* AGRA (the sine of amplitude), latitude and co-latitude &c. in this Armillary sphere as these places are in the heavens.

Questions regarding certain differences in the times and places of solar and lunar Eclipses.

If the middle of a lunar Eclipse takes place at the end of the TITHI (at the full moon), why does not the middle of the solar Eclipse take place in like manner at the change? Why is the Eastern limb of the Moon in a lunar Eclipse first involved in obscurity, and the western limb of the Sun first eclipsed in a solar Eclipse ?†

Questions regarding the parallaxes.

9. What, O most intelligent one, is the LAMBANA‡ and what is the NATI? why is the LAMBANA applied to the TITHI and the NATI applied to the latitude (of the Moon)? and why are these corrections settled by means (of the radius) of the Earth?

Questions regarding the phases of the Moon.

10. Ah! why, after being full, does the Moon, having lost her pure brightness, lose her circularity, as it were, by her too close association, caused by her diurnal revolution with the night: and why again after having arrived in the same sign as the Sun, does she thenceforth, by successive augmentation of her pure

* [SAMA-SA'NKU is the sine of the Sun's altitude when it comes to the prime vertical. B. D.]

† [An Eclipse of the Moon is caused by her entering into the Earth's shadow and as the place of the Earth's shadow and that of the Moon is the same at the full moon, the conjunction of the Earth's shadow and the Moon must happen at the same time; and an Eclipse of the Sun is caused by the interposition of the Moon between the Earth and the Sun, and the conjunction of the Sun and Moon in like manner must happen at the new moon, as then the place of the Sun and Moon is the same. As this is the case with the eclipses of both of them (i. e. both the Sun and Moon) the querist asks, "If the middle of a lunar eclipse &c." It is scarcely necessary to add that the assumption that the middle of a lunar eclipse takes place exactly at the full moon, is only approximately correct. B. D.]

‡ [The LAMBANA is equivalent to the Moon's parallax in longitude from the Sun reduced into time by means of the Moon's motion from the Sun: and the NATI is the same as the Moon's parallax in latitude from the Sun. B. D.]

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brightness, as from association with the Sun, attain her circular form ?*

End of the second Chapter.

CHAPTER III.

Called Bhuvana-kos'a or Cosmography.

The excellence of the Supreme Being.

1. The Supreme Being PARA BRAHMA the first principle, excels eternally. From the soul (PURUSHA) and nature (PRAKRITI,) when excited by the first principle, arose the first Great Intelligence called the MAHATTATTWA or BUDDHITATTWA: from it sprung self-consciousness (AHANKÁRA :) from it were produced the Ether, Air, Fire, Water, and Earth; and by the combination of these was made the universe BRAHMÁNḌA, in the centre of which is the Earth: and from BRAHMÁ CHATURÁNANA, residing on the surface of the Earth, sprung all animate and inanimate things.

Description of the Earth.

2. This Globe of the Earth formed of (the five elementary principles) Earth, Air, Water, the Ether, and Fire, is perfectly round, and encompassed by the orbits of the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, and by the constellations. It has no (material) supporter; but stands firmly in the expanse of heaven by its own inherent force. On its surface throughout subsist (in security) all animate and inanimate objects, DANUJAS and human beings, Gods and DAITYAS.

* This verse has a double meaning, all the native writers, however grave the subject, being much addicted to conceits. The second interpretation of this verse is as follows:

Ah! why does the most learned of Brahmans, though distinguished by his immaculate conduct, lose his pure honour and influence as it were from his misconduct caused by derangement? It is no wonder that the said Brahman after having met with a Brahman skilled in the VEDAS, and by having recourse to him, thenceforth becomes distinguished for his eminent good conduct by gradual augmentation of his illustriousness. L. W.

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3. It is covered on all sides with multitudes of mountains, groves, towns and sacred edifices, as is the bulb of the Nauclea's globular flower with its multitude of anthers.

Refutation of the supposition that the Earth has successive supporters.

4. If the Earth were supported by any material substance or living creature, then that would require a second supporter, and for that second a third would be required. Here we have the absurdity of an interminable series. If the last of the series be supposed to remain firm by its own inherent power, then why may not the same power be supposed to exist in the first, that is in the Earth? For is not the Earth one of the forms of the eight-fold divinity i. e. of S'IVA.

Refutation of the objection, as to how the Earth has its own inherent power.

5. As heat is an inherent property of the Sun and of Fire, as cold of the Moon, fluidity of water, and hardness of stones, and as the Air is volatile, so the earth is naturally immoveable. For oh! the properties existing in things are wonderful.

6. The* property of attraction is inherent in the Earth. By this property the Earth attacts any unsupported heavy thing towards it: The thing appears to be falling [but it is in a state of being drawn to the Earth]. The etherial expanse being equally outspread all around, where can the Earth fall?

Opinion of the BAUDDHAS.

7. Observing the revolution of the constellations, the BAUDDHAS thought that the Earth had no support, and as no heavy body is seen stationary in the air, they asserted that the earth† goes eternally downwards in space.

Opinion of the JAINAS.

8. The JAINAS and others maintain that there are two Suns and two

* [It is manifest from this that neither can the Earth by any means fall downwards, nor the men situated at the distances of a fourth part of the circumference from us or in the opposite hemisphere. B. D.]

† [He who resides on the Earth, is not conscious of the motion of it downwards in space, as a man sitting on a moving ship does not perceive its motion, B. D.]

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Moons, and also two sets of constellations, which rise in constant alternation. To them I give this appropriate answer.

Refutation of the opinion of the BAUDDHAS.

9. Observing as you do, O BAUDDHA, that every heavy body projected into the air, comes back again to, and overtakes the Earth, how then can you idly maintain that the Earth is falling down in space? [If true, the Earth being the heavier body, would, he imagines*—perpetually gain on the higher projectile and never allow its overtaking it.]

Refutation of the opinion of the JAINAS.

10. But what shall I say to thy folly, O JAINA, who without object or use supposest a double set of constellations, two Suns and two Moons? Dost thou not see that the visible circumpolar constellations take a whole day to complete their revolutions?

Refutation of the supposition that the Earth is level.

11. If this blessed Earth were level, like a plane mirror, then why is not the sun, revolving above at a distance from the Earth, visible to men as well as to the Gods? (on the PAURÁṆIKA hypothesis, that it is always revolving about MERU, above and horizontally to the Earth.

12. If the Golden mountain (MERU) is the cause of night, then why is it not visible when it intervenes between us and the Sun? And MERU being admitted (by the PAURÁṆIKAS) to lie to the North, how comes it to pass that the Sun rises (for half the year) to the South?

Reason of the false appearance of the plane form of the Earth.

13. As the one-hundredth part of the circumference of a circle is (scarcely different from) a plane, and as the Earth is an excessively large body, and a man exceedingly small (in comparison,) the whole visible portion of the Earth consequently appears to a man on its surface to be perfectly plane.

* [This was BHASKARA's own notion;—but even on the more correct principle, that all bodies fall with equal rapidity, the argument holds good. B. D.]

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Proof of the correctness of alleged circumference of the Earth.

14. That the correct dimensions of the circumference of the Earth have been stated may be proved by the simple Rule of proportion in this mode: (ascertain the difference in YUJANAS between two towns in an exact north and south line, and ascertain also the difference of the latitudes of those towns: then say) if the difference of latitude gives this distance in YUJANAS, what will the whole circumference of 360 degrees give?

To confirm the same circumference of the Earth.

15. As it is ascertained by calculation that the city of UJJAYINÍ is situated at a distance from the equator equal to the one-sixteenth part of the whole circumference: this distance, therefore, multiplied by 16 will be the measure of the Earth's circumference. What reason then is there in attributing (as the PAURÁṆIKAS do) such an immense magnitude to the earth?

16. For the position of the moon's cusps, the conjunction of the planets, eclipses, the time of the risings and settings of the planets, the lengths of the shadows of the gnomon, &c., are all consistent with this (estimate of the extent of the) circumference, and not with any other; therefore it is declared that the correctness of the aforesaid measurement of the earth is proved both directly and indirectly,—(directly, by its agreeing with the phenomena;—indirectly, by no other estimate agreeing with the phenomena).

17. LANKÁ is situated in the middle of the Earth: YAMAKOTI is situated to the East of LANKÁ, and ROMAKAPATTANA to the west. The city of SIDDHAPURA lies underneath LANKÁ. SUMERU is situated to the North (under the North Pole,) and VADAVÁNALA to the South of LANKÁ (under the south Pole):

18. These six places are situated at a distance of one-fourth part of the Earth's circumference each from its adjoining one. So those who have a knowledge of Geography maintain. At MERU reside the Gods and the SIDDHAS, whilst at VADAVÁNALA are situated all the hells and the DAITYAS.

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19. A man on whatever part of the Globe he may be, thinks the Earth to be under his feet, and that he is standing up right upon it: but two individuals placed at 90° from each other, fancy each that the other is standing in a horizontal line, as it were at right angles to himself.

20. Those who are placed at the distance of half the Earth's circumference from each other are mutually antipodes, as a man on the bank of a river and his shadow reflected in the water: But as well those who are situated at the distance of 90° as those who are situated at that of 180° from you, maintain their positions without difficulty. They stand with the same ease as we do here in our position.

Positions of the Dwípas and Seas.

21. Most learned astronomers have stated that Jambúdwípa embraces the whole northern hemisphere lying to the north of the salt sea: and that the other six Dwípas and the (seven) Seas viz. those of salt, milk, &c. are all situated in the southern hemisphere.

22. To the south of the equator lies the salt sea, and to the south of it the sea of milk, whence sprung the nectar, the Moon and the Goddess Lakshmí, and where the Omnipresent Vásudeva, to whose Lotus-feet Brahmá and all the Gods bow in reverence, holds his favorite residence.

23. Beyond the sea of milk lie in succession the seas of curds, clarified butter, sugar-cane-juice, and wine: and, last of all, that of sweet Water, which surrounds Vadavánala. The Pátála Lokas or infernal regions, form the concave strata of the Earth.

24. In those lower regions dwell the race of serpents (who live) in the light shed by the rays issuing from the multitude of the brilliant jewels of their crests, together with the multitude of Asuras; and there the Siddhas enjoy themselves with the pleasing persons of beautiful females resembling the finest gold in purity.

25. The S'áka, S'álmala, Kaus'a, Kráuncha, Gomedaka, and

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PUSHKARA DWÍPAS are situated [in the intervals of the above mentioned seas] in regular alternation: each Dwípa lying, it is said, between two of these seas.

Positions of the Mountains in JAMBÚ DWÍPA and its nine KHAṆḌAS parts caused by the mountains.

26. To the North of LANKÁ lies the HIMÁLAYA mountain, and beyond that the HEMAKÚṬA mountain and beyond that again the NISHADHA mountain. These three Mountains stretch from sea to sea. In like manner to the north of SIDDHAPURA lie in succession the S'ṚINGAVÁN S'UKLA and NÍLA mountains. To the valleys lying between these mountains the wise have given the name of VARSHAS.

27. This valley which we inhabit is called the BHÁRATA-VARSHA; to the North of it lies the KINNARAVARSHA, and beyond it again the HARIVARSHA, and know that the north of SIDDHAPURA in like manner are situated the KURU, HIRAṆMAYA and RAMYAKA VARSHAS.

28. To the north of YAMAKOṬI lies the MÁLYAVÁN mountain, and to the north of ROMAKAPATTANA the GANDHAMÁDANA mountain. These two mountains are terminated by the NÍLA and NISHADHA mountains, and the space between these two is called the ILÁVṚITA VARSHA.

29. The country lying between the MÁLYAVÁN mountain and the sea, is called the BHADRÁS'WA-VARSHA by the learned; and geographers have denominated the country between the GANDHAMÁDANA and the sea, the KETUMÁLA-VARSHA.

30. The ILÁVṚITA-VARSHA, which is bounded by the NISHADHA, NÍLA, GANDHAMÁDANA and MALYAVÁN mountains, is distinguished by a peculiar splendour. It is a land rendered brilliant by its shining gold, and thickly covered with the bowers of the immortal Gods.

Position of the mountain MERU in ILÁVṚITA.

31. In the middle of the ILÁVṚITA VARSHA stands the mountain MERU, which is composed of gold and of precious stones, the abode of the immortal Gods. Expounders of the Puráṇas have further described this MERU to be the pericarp of the earth-lotus whence BRAHMÁ had his birth.

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32. The four mountains MANDARA, SUGANDHA, VIPULA and SUPÁRS'WA serve as buttresses to support this MERU, and upon these four hills grow severally the KADAMBA, JAMBÚ, VAṬA and PIPPALA trees which are as banners on those four hills.

33. From the clear juice which flows from the fruit of the JAMBÚ springs the JAMBÚ-NADÍ; from contact with this juice earth becomes gold: and it is from this fact that gold is called JÁMBÚNADA: [this juice is of so exquisite a flavour that] the multitude of the immortal Gods and SIDDHAS, turning with distaste from nectar, delight to quaff this delicious beverage.

34. And it is well known that upon those four hills [the buttresses of MERU] are four gardens, (1*st*) CHAITRARATHA of varied brilliancy [sacred to KUBERA], (2*nd*) NANDANA which is the delight of the APSARAS, (3*rd*) the DHṚITI which gives refreshment to the Gods, and (4*th*) the resplendent VAIBHRÁJA.

35. And in these gardens are beautified four reservoirs, viz. the ARUṆA, the MÁṆASA, the MAHÁHRADA and the S'WETA-JALA, in due order: and these are the lakes in the waters of which the celestial spirits, when fatigued with their dalliance with the fair Goddesses, love to disport themselves.

36. MERU divided itself into three peaks, upon which are situated the three cities sacred to VISHNU, BRAHMÁ and S'IVA [denominated VAIKUNTHA, BRAHMAPURA, and KAILÁSA], and beneath them are the eight cities sacred to INDRA, AGNI, YAMA, NAIRṚITA, VARUṆA, VÁYU, S'AS'Í, and Ís'a, [i. e. the regents of the eight DIKS or directions,* viz., the east sacred to

* [As the point where the equator cuts the horizon is the east, the sun therefore rises due east at time of the equinoxes but on this ground, we cannot determine the direction at MERU [the north pole] because there the equator coincides with the horizon and consequently the sun moves at MERU under the horizon the whole day of the equinox. Yet the ancient astronomers maintained that the direction in which the YAMAKOṬI lies from MERU is the east, because, according to their opinion, the inhabitants of MERU saw the sun rising towards the YAMAKOṬI at the beginning of the KALPA. In the same manner, the direction in which LANKÁ lies from mount MERU is south, that in which ROMAKAPATTANA lies, is west, and the direction in which SIDDHA-

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INDRA, the south-east sacred to AGNI, the south sacred to YAMA, the south-west sacred to NAIRṚITA, the west sacred to VARUṆA, the north-west sacred to VA'YU, the north sacred to S'as'í and the north-east sacred to Í's'A.]

Some peculiarity.

37. The sacred Ganges, springing from the Foot of VISHNU, falls upon mount MERU, and thence separating itself into four streams descends through the heavens down upon the four VISHKAMBHAS or buttress hills, and thus falls into the four reservoirs [above described].

38. [Of the four streams above mentioned], the first called SÍTA', went to BHADRA'S'WA-VARSHA, the second, called ALAKANANDÁ, to BHÁRATA-VARSHA, the third, called CHAKSHU, to KETUMÁLA-VARSHA, and the fourth, called BHADRA' to UTTARA KURU [or North KURU].

39. And this sacred river has so rare an efficacy that if her name be listened to, if she be sought to be seen, if seen, touched or bathed in, if her waters be tasted, if her name be uttered, or brought to mind, and her virtues be celebrated, she purifies in many ways thousands of sinful men [from their sins].

40. And if a man make a pilgrimage to this sacred stream, the whole line of his progenitors, bursting the bands [imposed on them by YAMA], bound away in liberty, and dance with joy; nay even, by a man's approach to its banks they repulse the slaves of YAMA [who kept guard over them], and, escaping from NARAKA [the infernal regions], secure an abode in the happy regions of Heaven.

PURA lies from MERU is north. The buttresses of MERU, MANDARA, SUGANDHA, &c. are situated in the east, south &c. from MERU respectively. B. D.]

Note on verses from 21 to 43 :—BHASKARA'CHA'RYA has exercised his ingenuity in giving a locality on the earth to the poetical imaginations of VYA'SA, at the same time that he has preserved his own principles in regard to the form and dimensions of the Earth. But he himself attached no credit to what he has described in these verses for he concludes his recital in his commentary with the words,

यदिदमुक्तं तत् सव पुराणाश्रितम् ।

"What is stated here rests all on the authority of the PURÁṆAS." As much as to say "credat Judæus." L. W.

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The 9 KHANDAS and 7 KULÁCHALAS of BHA'RATA-VARSHA.

41. Here in this BHÁRATA-VARSHA are embraced the following nine KHANDAS [portions] viz. AINDRA, KAS'ERU, TÁMRAPARNA, GABHASTIMAT, KUMARIKÁ, NÁGA, SAUMYA, VÁRUNA, and lastly GÁNDHARVA.

42. In the KUMÁRIKÁ alone is found the subdivision of men into castes; in the remaining KHANDAS are found all the tribes of ANTYAJAS or outcaste tribes of men. In this region [BHÁRATA-VARSHA] are also seven KULÁCHALAS, viz. the MÁHENDRA, S'UKTI, MALAYA, RIKSHAKA, PÁRIYÁTRA, the SAHYA, and VINDHYA hills.

Arrangement of the seven LOKAS worlds.

43. The country to the south of the equator is called the BHÚRLOKA, that to the north the BHUVALOKA and MERU [the third] is called the SWARLOKA, next is the MAHARLOKA in the Heavens beyond this is the JANALOKA, then the TAPOLOKA and last of all the SATYALOKA. These LOKAS are gradually attained by increasing religious merits.

44. When it is sunrise at LANKÁ, it is then midday at YAMAKOTI (90° east of LANKÁ), sunset at SIDDHAPURA and midnight at ROMAKAPATTANA.

Points of the compass why MERU is due north of all places.

45. Assume the point of the horizon at which the sun rises as the east point, and that at which he sets as the west point, and then determine the other two points, i. e., the north and south through the MATSYA* effected by the east and west points. The line connecting the north and south points will be a meridian line and this line in whatever place it is drawn will fall upon the north point: hence MERU lies due north of all places.

A curious fact is rehearsed. Geographical Anomaly.

46. Only YAMAKOTI lies due east from UJJAYINÍ, at the distance of 90°

* [From the east and west points, as centres, with a common radius describe two arcs, intersecting each other in two points, the place contained by the arcs is called MATSYA "a fish" and the intersecting points are the north and south points. B. D.]

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from it: but LANKÁ and not UJJAYINÍ lies due west from YAMAKOṬI.

47. The same is the case everywhere; no place can lie west of that which is to its east except on the equator, so that east and west are strangely related.*

Right sphere.

48. A man situated on the equator sees both the north and south poles touching [the north and south points of] the horizon, and the celestial sphere resting (as it were) upon the two poles as centres of motion and revolving vertically over his head in the heavens, as the Persian water-wheel.

Oblique sphere.

49. As a man proceeds north from the equator, he observes the constellations [that revolve vertically over his head when seen from the equator] to revolve obliquely, being deflected from his vertical point: and the north pole elevated above his horizon. The degrees between the pole and the horizon are the degrees of latitude [at the place]. These degrees are caused by the YOJANAS [between the equator and the place].

How the degrees of latitude are produced from the distance in YOJANAS and vice versâ.

50. The number of YOJANAS [in the arc of any terrestrial or celestial circle] multiplied by 360 and divided by [the number in YOJANAS in] the circumference of the circle is the number of degrees [of that arc] in the earth or in the planetary orbit in the heavens. The YOJANAS are found from the degrees by reversing the calculation.

Parallel sphere.

51. The Gods who live in the mount MERU observe at their zenith

[* As the sun or any heavenly body when it reaches the Prime Vertical of any place is called due east or west, so according to the Hindu Astronomical language all the places on the Earth which are situated on the circle corresponding to the Prime Vertical are due east or west from the place and not those which are situated on the parallel of latitude of the place, that is the places which have the angle of position 90° from any place are due east or west from that place. And thus all directions on the Earth are shown by means of the angle of position in the Hindu Astronomical works. B. D.]

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the north pole, while the DAITYAS in VADAVÁNALA the south pole. But while the Gods behold the constellations revolving from left to right, to the DAITYAS they appear to revolve from right to left. But to both Gods and DAITYAS the equatorial constellations appear to revolve on and correspond with the horizon.

Dimensions of the Earth's circumference.

52. The circumference of the earth has been pronounced to be 4967 YOJANAS and the diameter of the same has been declared to be $1581\frac{1}{24}$ YOJANAS in length: the superficial area of the Earth, like the net enclosing the hand ball, is 78,53,034 square YOJANAS, and is found by multiplying the circumference by the diameter.*

The error of Lalla is exposed in regard to the superficial area of the Earth.

53. The superficial area of the Earth, like the net enclosing the hand ball, is most erroneously stated by LALLA: the true area not amounting to one hundredth part of that so idly assumed by him. His dimensions are contrary to what is found by actual inspection: my charge of error therefore cannot be pronounced to be rude and uncalled for. But if any doubt be entertained, I beg you, O learned mathematicians, to examine well and with the utmost impartiality whether the amount stated by me or that stated by him is the correct one. [The amount stated by LALLA in his

* [The diameter and the circumference of the Earth here mentioned are to each other as 1250: 3927 and the demonstration of this ratio is shown by BHÁSKARÁCHÁRYA in the following manner.

Take a radius equal to any large number, such as more than 10000, and through this determine the sine of a smaller arc than even the 100th part of the circumference of the circle by the aid of the canon of sines (JYOTPATTI,) and the sine thus determined when multiplied by that number which represents the part which the arc just taken is of the circumference, becomes the length of circumference because an arc smaller than the 100th part of the circumference of a circle is [scarcely different from] a straight line. For this reason, the circumference equal to the number 62832 is granted by ARYABHATTA and the others, in the diameter equal to the number 20,000. Though the length of the circumference determined by extracting the square root of the tenfold square of the diameter is rough, yet it is granted for convenience by SRIDHARÁCHA'RYA, BRAHMAGUPTA and the others, and it is not to be supposed that they were ignorant of this roughness.—B. D,]

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work entitled DHÍVṚIDDHIDA-TANTRA is 285,63,38,557 square YOJANAS, which he appears to have found by multiplying the square contents of the circle by the circumference.]

Shows the wrongness of the Rule given by Lalla.

54. If a piece of cloth be cut in a circular form with a diameter equal to half the circumference of the sphere, then half of the sphere will be (entirely) covered by that circular cloth and there will still be some cloth to spare.

55. As the area of this piece of cloth is to be found nearly 2½ times the area of a great circle of the sphere: and the area of the piece of cloth covering the other half of the sphere is also the same; *

56. Therefore the area of the whole sphere cannot be more than 5 times the area of the great circle of the sphere. How then has he multiplied [the area of the great circle of the sphere] by the circumference [to get the superficial contents of the sphere] ?

57. As the area of a great circle [of the sphere] multiplied by the circumference is without reason, the rule (therefore of LALLA for the superficial contents of the sphere) is wrong, and the superficial area of the Earth (given by him) is consequently wrong.

Otherwise.

58, 59. Suppose the length of the [equatorial] circumference of the globe equal to 4 times the number of sines [viz. 96, there being 24 sines calculated for every 3°¾, which number multiplied by 4 = 96] and such oblong sections equal to the number of the length of the said circumference and marked with the vertical lines [running from pole to pole], as there are seen formed by nature on the ÁNWLÁ fruit marked off by the lines running from the top of it to its bottom.

* Let the diameter of a sphere be 7: the circumference will be 22 nearly. The area of a circle whose diameter is 7 will be about 38½; that of a circle whose diameter is 11 (½ circumference) will be about 89 6/7 this 89 6/7 is little less than 2½ times 38½. L. W.

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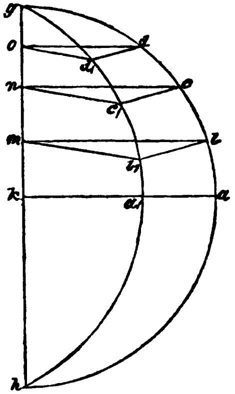
60. If we determine the superficial area of one of these sections by means of its parts, we have it in this form. Sum of all the sines diminished by half of the radius and divided by the same.*

* The correctness of this form is thus briefly illustrated by BHA'SKARA'CHA'RYA in his commentary.



Let $g\,a\,h\,a_1\,g$ be the section in which ab, $b\,c$, $c\,d$ &c. and a_1b_1, b_1c_1, c_1d_1, &c. are each equal to 1 cubit and also aa_1 arc equal to 1 cubit: then bb_1, cc_1, dd_1, &c. are proportional to the sines $m\,b$, $n\,c$, $o\,d$, &c. and are thus found.

If ka or rad : give, aa 1 (= 1) : : mb : $bb_1 = \dfrac{mb.}{Rad.}$

If Rad : 1 : : nc : $cc_1 = \dfrac{nc}{Rad}$

again Rad : 1 : : od : $dd_1 = \dfrac{od}{Rad}$

&c.

Now aa_1, bb_1, cc_1, &c. being found, the contents of each of $aa_1\,b_1b$, $bb_1\,c_1c$, $cc_1\,d_1d$, &c. the part of the section is found by taking half the sum of aa_1 & bb_1 bb_1 & cc_1, cc_1 & dd_1 &c. and multiplying it by ab (which is equal to each of bc, cd, &c.) here ab is assumed as 1 and the whole surface each of aa_1b_1b, bb_1c_1c as a plane, for an arc of 3°$\frac{3}{4}$ is scarcely different from a plane.

Now to find the sum of aa_1b_1b, bb_1c_1c &c. we have

$$\frac{aa_1 + bb_1}{2} \times 1 + \frac{bb_1 + cc_1}{2} \times 1 + \frac{cc_1 + dd_1}{} \times 1 + \&c.$$

adding these and leaving out 1 multiplier, we have

$$\tfrac{1}{2}\,aa_1 + bb_1 + cc_1 + dd_1 + \&c.$$

Substituting the values of aa_1, bb_1, &c. we have

$$\tfrac{1}{2} + \frac{mb}{R} + \frac{nc}{R} + \frac{od}{R} + \&c. \text{ so on for the assumed sines}$$

$$\text{but } \tfrac{1}{2} = \frac{\frac{1}{2}R}{R} = \frac{R}{R} - \frac{\frac{1}{2}R}{R}$$

By substitution we get

$$\frac{R}{R} + \frac{mb}{R} + \frac{nc}{R} + \&c. \ldots - \frac{\frac{1}{2}R}{R}$$

$$= \frac{R + mb + nc + od + \&c \ldots - \frac{1}{2}R}{R}$$

It is evident from this that the sum of all the sines diminished by the half of the Radius and divided by the Radius is equal to the contents of the upper half of the section, therefore by dividing by $\frac{1}{2}$ Rad we get the whole section instead of only the upper half of it.

$$\text{i. e. contents of the whole section} = \frac{\text{sum of all the sines} - \frac{1}{2}R.}{\frac{1}{2}R} = A.$$

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61. As the superficial area of one section thus determined is equal to the diameter of the globe, the product found by multiplying the diameter by the circumference has therefore been asserted to be the superficial contents of a sphere.

The grand deluges or dissolutions.

62. The earth is said to swell to the extent of one YOJANA equally all around [from the centre] in a day of BRAHMÁ by reason of the decay of the natural productions which grow upon it: in the BRÁHMA deluge that increase is again lost. In the grand deluge [in which BHAHMÁ himself as well as all nature fades away then] the Earth itself is reduced to a state of nonentity.

Are four-fold.

63. That extinction which is daily taking place amongst created beings is called the DAINANDINA or daily extinction. The BRÁHMA extinction or deluge takes place at the end of BRAHMÁ's day: for all created beings are then absorbed in Brahmá's body.

64. As on the extinction of BRAHMÁ himself all things are dissolved into nature, wise men therefore call that dissolution the PRÁKṚITIKA or resolution into nature. Things thus in a state of extinction having their destinies severally fixed are again produced in separate forms when nature is excited (by the Creator).

65. The devout men, who have destroyed all their virtues and sins by a knowledge of the soul, having abstracted their minds from worldly acts, concentrate their thoughts on the

Here, by substituting the values of the 24 sines stated in the GAṆITA'DHA'YA we have

$A = 30\frac{6}{1}\frac{5}{3}$ viz. the diameter of the globe where the circumference = 96. L. W.

[Here, the demonstration of the rule (multiply the superficial area of the sphere by the diameter and divide the product by 6) for finding out the solid content of the sphere is shown by BHA'SKARA'CHA'RYA in the following manner.

Suppose in the sphere the number of pyramids, the height of which is equal to the radius and whose bases are squares having sides equal to 1, equal to the number of the superficial area of the sphere, then

The solid contents of every pyramid $= \frac{1}{3}$ R.

$= \frac{1}{6}$ diameter

and the number of pyramids in the sphere is equal to the number of the superficial contents of the sphere.

∴ The solid content of the sphere $= \frac{1}{6}$ diameter × superficial area.—B.D.]

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Supreme Being, and after their death, as they attain the state from which there is no return, the wise men therefore denominate this state the ÁTYANTIKA dissolution. Thus the dissolutions are four-fold.

The universe.

66. The earth and its mountains, the Gods and DÁNAVAS, men and others and also the orbits of the constellations and planets and the LOKAS which, it is said, are arranged one above the other, are all included in what has been denominated the BRAHMÁṆḌA (universe).

Dimensions of the BRAHMA'ṆḌA.

67. Some astronomers have asserted the circumference of the circle of Heaven to be 18,712,069,200,000,000 YOJANAS in length. Some say that this is the length of the zone which binds the two hemispheres of the BRAHMÁṆḌA. Some PAURÁṆIKAS say that this is the length of the circumference of the LOKÁLOKA PARVATA.*

* Vide verses 67,68,69, BHA'SKARA'CHA'RYA does not answer the objection which these verses supply to his theory of the Earth being the centre of the system. The Sun is here made the principal object of the system—the centre of the BRAHMA'ṆḌA—the centre of light whose boundary is supposed fixed: but if the Sun moves then the Hindoo BRAHMA'ṆḌA must be supposed to be constantly changing its Boundaries. Subbuji Bápú had not failed to use this argument in favour of the Newtonian system in his S'IROMAṆI PRAKA'S'A, vide pages 55, 56. BHA'SKARA'CHA'RYA however denies that he can father the opinion that this is the length of the circumference limiting the BRAHMA'ṆḌA and thus saves himself from a difficulty. L. W.

[Mr. Wilkinson has thus shown the objection which Subbàje Bápú made to the assumption of the Sun's motion, but I think that the objection is not a judicious one. Because had the length of the circumference of the BRAHMA'ṆḌA been changed on account of the alteration of the boundary of the Sun's light with him, or had any sort of motion of the stars been assumed, as would have been granted if the earth is supposed to be fixed, then, the inconvenience would have occurred ; but this is not the case. In fact, as we cannot fix any boundary of the light which issued from the sun, the stated length of the circumference of the BRAHMÁṆḌA is an imaginary one. For this reason, BHÁSKARÁCHÁRYA does not admit this stated length of the circumference of the BRAHMA'ṆḌA. He stated in his GAṆITA'DHYAYA' in the commentary on the verse 68th of this Chapter that "those only, who have a perfect knowledge of the BRAHMA'ṆḌA as they have of an A'NVALA' fruit held in their palm, can say that this length of the circumference of the BRAHMA'ṆḌA is the true one;" that is, as it is not in man's power to fix any limit of the BRAHMA'ṆḌA, the said limit is unreasonable. Therefore no objection can be possibly made to the system that the Sun moves, by assuming such an imaginary limit of the BRAHMÁṆḌA which is little less impossible than the existence of the heavenly lotus.—B. D.]

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68. Those, however, who have had a most perfect mastery of the clear doctrine of the sphere, have declared that this is the length of that circumference bounding the limits, to which the darkness dispelling rays of the Sun extend.

69. But let this be the length of the circumference of the BRAHMÁṆDA or not: [of that I have no sure knowledge] but it is my opinion that each planet traverses a distance corresponding to this number of YOJANAS in the course of a KALPA or a day of BRAHMÁ and that it has been called the KHAKAKSHÁ by the ancients.

End of third Chapter called the BHUVANA-KOS'A or cosmography.

CHAPTER IV.

CALLED MADHYA-GATI-VÁSANÁ.

On the principles of the Rules for finding the mean places of the Planets.

Places of the several winds.

1. The seven [grand] winds have thus been named: viz.—

1st. The Ávaha or atmosphere.
2nd. The Pravaha beyond it.
3rd. The Udvaha.
4th. The Samvaha.
5th. The Suvaha.
6th. The Parivaha.
7th. The Parávaha.

2. The atmosphere extends to the height of 12 YOJANAS from the Earth: within this limit are the clouds, lightning, &c. The Pravaha wind which is above the atmosphere moves constantly to the westward with uniform motion.

3. As this sphere of the universe includes the fixed stars and planets, it therefore being impelled by the Pravaha wind, is carried round with the stars and planets in a constant revolution.

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An illustration of the motion of the planets.

4. The Planets moving eastward in the Heavens with a slow motion, appear as if fixed on account of the rapid motion of the sphere of the Heavens to the west, as insects moving reversely on a whirling potter's wheel appear to be stationary [by reason of their comparatively slow motion].

Sidereal and terrestrial days and their lengths.

5. If a star and the Sun rise simultaneously [on any day], the star will rise again (on the following morning) in 60 sidereal GHAṬIKÁS: the Sun, however, will rise later by the number of ASUS (sixths of a sidereal minute), found by dividing the product of the Sun's daily motion [in minutes] and the ASUS which the sign, in which the Sun is, takes in rising, by 1800 [the number of minutes which each sign of the ecliptic contains in itself].

6. The time thus found added to the 60 sidereal GHAṬIKÁS forms a true terrestrial day or natural day. The length of this day is variable, as it depends on the Sun's daily motion and on the time [which different signs of the ecliptic take] in rising, [in different latitudes: both of which are variable elements].*

* [Had the Sun moving with uniform motion on the equinoctial, the each minute of which rises in each ASU, the number of ASUS equal to the number of the minutes of the Sun's daily motion, being added to the 60 sidereal GHAṬIKAS, would have invariably made the exact length of the true terrestrial day as LALLA and others say. But this is not the case, because the Sun moves with unequal motion on the ecliptic, the equal portions of which do not rise in equal times on account of its being oblique to the equinoctional. Therefore, to find the exact length of the true terrestrial day, it is necessary to determine the time which the minutes of the Sun's daily motion take in rising and then add this time to 60 sidereal GHAṬIKA'S. For this reason, the terrestrial day determined by LALLA and others is not a true but it is a mean.

The difference between the oblique ascension at the beginning of any given day, and that at the end of it or at the beginning of the next day, is the time which the minutes of the Sun's motion at the day above alluded to take in rising, but as this cannot be easily determined, the ancient Astronomers having determined the periods which the signs of the ecliptic take in rising at a given place, find the time which any portion of a given sign of the ecliptic takes in rising, by the following proportion.

If 30° or 1800′ of a sign : take number of the ASUS (which any given sign of the ecliptic takes) in rising at a given place : : what time will any portion of the sign above alluded to take in rising?

The calculation which is shown in the 5th verse depends on this proportion.—B. D.]

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Revolutions of the Sun in a year are less than the revolutions of stars by one.

7. A sidereal day consists invariably of 60 sidereal GHAṬIKÁS: a mean SÁVANA day of the Sun or terrestrial day consists of that time with an addition of the number of ASUS equal to the number of the Sun's daily mean motion [in minutes]. Thus the number of terrestrial days in a year is less by one than the number of revolutions made by the fixed stars.

Length of solar year.

8. The length of the (solar) year is 365 days, 15 GHAṬIKÁS, 30 PALAS, 22½ VIPALAS reckoned in BHÚMI SÁVANA or terrestrial days: The $\frac{1}{12}$th of this is called a SAURA (solar) month, viz. 30 days, 26 GHAṬIKÁS, 17 PALAS, 31 VIPALAS, 52½ PRAVIPALAS. Thirty SÁVANA or terrestrial days make a SÁVANA month.*

Length of lunar month or lunation.

9. The time in which the Moon [after being in conjunction with the Sun] completing a revolution with the difference between the daily motion and that of the Sun, again overtakes the Sun, (which moves at a slower rate) is called a Lunar month. It is 29 days, 31 GHAṬIKÁS, 50 PALAS in length.†

The reason of additive months called ADHIMA'SAS.

10. An ADHIMÁSA or additive month which is lunar, occurs in the duration of 32½ SAURA (solar) months found by dividing the lunar month by the difference between this and the SAURA month. From

* [Here a solar year consists of 365 days, 15 GHAṬIKÁS, 30 PALAS, 22½ VIPALAS, i. e. 365 *d.* 6 *h.* 12 *m.* 9 *s.* and in SÚRYA-SIDDHA'NTA the length of the year is 365 *d.* 15 *g.* 31 *p.* 31. 4 *v.* i. e. 365 *d.* 6 *h.* 12 *m.* 36. 56 *s.*—B. D.]

[† That lunar month which ends, when the Sun is in MESHA stellar Aries is called CHAITRA and that which terminates when the Sun is in VṚISHABHA stellar Taurus, is called VAIS'AKHA and so on. Thus, the lunar months corresponding to the 12 stellar signs MESHA (Aries) VṚISHABHA (Taurus) MITHUNA (Gemini) KARKA (Cancer), SINHA (Leo), KANYA' (Virgo), TULA' (Libra), VRIS'CHIKA (Scorpio), DHANU (Sagittarius), MAKARA (Capricornus), KUMBHA (Aquarius) and MINA (Pisces), are CHAITRA, VAIS'A'KHA, JYESHṬHA, A'SHA'ḌHA S'RA'VAṆA, BHA'DRAPADA, A'S'WINA, KA'RTIKA, MA'RGAS'ÍRSHA, PAUSHA, MA'GHA, and PHALGUNA. If two lunar months terminate when the Sun is only in one stellar sign, the second of these is called ADHIMA'SA an additive month. The 30th part of a lunar month is called Tithi (a lunar day).—B. D.]

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this, the number of the additive months in a KALPA may also be found by proportion.*

11. As a mean lunar month is shorter in length than a mean SAURA month, the lunar months are therefore more in number than the SAURA in a KALPA. The difference between the number of lunar and SAURA months in a KALPA is called by astronomers the number of ADHIMA'SAS in that period.

The reason of subtractive day called AVAMA.

12. An AVAMA or subtractive day which is SA'VANA occurs in $64\frac{1}{11}$ TITHIS (lunar days) found by dividing 30 by the difference between the lunar and SA'VANA month. From this, the number of AVAMAS in a YUGA may be found by proportion.†

13.‡ If the ADHIMA'SAS are found from SAURA days or months, then the result found is in the lunar months, [as for instance in finding the AHARYANA. If in the SAURA days of a KALPA : are

* [After the commencement of a YUGA, a lunar month terminates at the end of AMAVA'SYA' (new moon) and a SAURA month at the mean VRISHABHA-SANKRA'NTI (i. e. when the mean Sun enters the second stellar sign) which takes place with 54 *g*. 27 *p*. 31 *v*. 52½ *p*. after the new moon. Afterwards a second lunar month ends at the 2nd new moon after which the MITHUNA-SANKRA'NTI takes place with twice the Ghatis. &c. above mentioned. Thus the following SANKRA'NTIS KARKA &c. take place with thrice four times &c. those GHAṬIS, &c. In this manner, when the SANKRA'NTI thus going forward, again takes place at new moon, the number of the passed lunar months exceeds that of the SAURA by one. This one month is called an additive month : and the SAURA months which an additive month requires for its happening can be found by the proportion as follows.

As 54 *ghatis*, 27 p. &c. the difference between a lunar and a saura
: One saura month
: : 29, 31, 50 the number terrestrial day &c. in a lunar month
: 32, 15, 31, &c. the number of saura months, days, &c.—B. D.]

† [At the beginning of a KALPA or a YUGA, the terrestrial and lunar days begun simultaneously, but the lunar day being less than the terrestrial day, terminated before the end of the terrestrial day, i. e. before the next sun-rise. The interval between the end of the lunar day and the next sunrise, is called AVAMA-S'ESHA the remainder of the subtractive day. This remainder increases every day, therefore, when it is 60 GHAṬIKÁS (24 hours), this constitutes a AVAMA day or subtractive day. The lunar days in which a subtractive day occurs, are found by the following proportion.

If 0 *d*. 28 *g*. 10 *p*. the difference between the lengths of terrestrial and of a lunar month.
: 1 lunar month or 30 tithis
: : a whole terrestrial day : $64\frac{1}{11}$ tithis nearly.—B. D.]

‡ The objects of these two verses seems not to be more than to assert that the fourth term of a proportion is of the same denomination as the 2nd.—L. W.

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so many ADHIMÁSAS : : then in given number of solar days; how many ADHIMÁSAS ?] If the ADHIMÁSAS are found from lunar days or months, then the result is in SAURA months, and the remainder is of the like denomination.

14. [In like manner] the AVAMAS or subtractive days if found from lunar days, are in SÁVANA time: if found from SÁVANA time they are lunar and the remainder is so likewise.

A question.

15. Why, O Astronomer, in finding the AHARGAṆA do you add SAURA months to the lunar months CHAITRA &c. [which may have elapsed from the commencement of the current year] : and tell me also why the [fractional] remainders of ADHIMÁSAS and AVAMA days are rejected: for you know that to give a true result in using the rule of proportion, remainders should be taken into account?

Reason of omitting to include the ADHIMÁSA S'ESHA in finding the AHARGAṆA.

16.* As the lunar month ends at the change of the Moon and the SUARA month terminates when the Sun enters a stellar sign, the accumulating portion of an ADHIMÁSA always lies after each new Moon and before the Sun enters the sign.

* [The meaning of these 4 verses will be well understood by a knowledge of the rule for finding the AHARGAṆA, we therefore show the rule here.

In order to find the AHARGANA (elapsed terrestrial days from the commencement of the KALPA to the required time) astronomers multiply the number of SAURA years expired from the beginning of the KALPA by 12, and thus they get the number of SAURA months till the last MESHA SANKRANTI (that is, the time when the Sun enters the 1st sign of the Zodiac called Aries.) To these months they add then the passed lunar months CHAITRA &c., considering them as SAURA. These SAURA months become, up to the time when the Sun enters the sign of the Zodiac corresponding to the required lunar month. They multiply then the number of these months by 30 and add to this product the number of the passed TITHIS (lunar days) of the required month considering them as SAURA days. The number of SAURA days thus found becomes greater than that of those till the end of the required TITHI by the ADHIMASA S'ETHA. To make these SAURA days lunar, they determine the elapsed additive months by the proportion in the following manner

As the number of SAURA days in a KALPA
: the number of additive months in that period
: : the number of SAURA days just found
: the number of additive months elapsed

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17. Now the number of TITHIS (lunar days) elapsed since the change of the Moon and supposed as if SAURA, is added to the number of SAURA days [found in finding the AHARGAṆA]: but as this number exceeds the proper amount by the quantity of the ADHIMÁSA-S'ESHA therefore the ADHIMÁS-SESHA is omitted [to be added].

18. [In the same manner] there is always a portion of a AVAMA-S'ESHA between the time of sun-rise and the end of the [preceding] TITHI. By omitting to subtract it, the AHARGAṆA is found at the time of sun-rise: if it were not omitted, the AHARGAṆA would represent the time of the end of the TITHI [which is not required but that of the sun-rise].

Reason of the correction called the UDAYÁNTARA KARMA.

19, 20, 21 and 22. As the true, terrestrial day is of variable length, the AHARGAṆA has been found in mean terrestrial days: the places of the planets found by this AHARGAṆA when rectified by the amount of the correction called the UDAYÁNTARA whether additive or subtractive will be found to be at the time of sun-rise at LANKÁ.* The ancient

If these additive months with their remainder be added to the SAURA days above found, the sum will be the number of lunar days to the end of the SAURA days, but we require it to the end of the required TITHI. And as the remainder of the additive months lies between the end of the TITHI and that of its corresponding SAURA days, they therefore add the whole number of ADHI-MÁSAS just found to that of the SAURA days omitting the remainder to find the lunar days to the end of the required TITHI. Moreover, to make these lunar days terrestrial, they determine AVAMA subtractive days by the proportion such as follows.

As the number of lunar days in a KALPA
: the number of subtractive days in that period
: : the number of lunar days just found
: the number of AVAMA elapsed with their remainder.

If these AVAMAS be subtracted with their remainder from the lunar days, the difference will be the number of the AVAMA days elapsed to the end of the required TITHI; but it is required at the time of sun-rise. And as the remainder of the subtractive days lies between the end of the TITHI and the sun-rise, they therefore subtract the AVAMAS above found from the number of lunar days omitting their remainder i. e. AVAMA-S'ESHA. Thus the AHARGAṆA itself becomes at the sun-rise.—B. D.]

* [If the Sun been moving on the equinoctial with an equal motion, the terrestrial day would have been of an invariable length and consequently the Sun would have reached the horizon at LANKÁ at the end of the AHARGAṆA which is an enumeration of the days of invariable length that is of the mean terrestrial days. But the Sun moves on the ecliptic whose equal parts do not

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Astronomers have not thus rectified the places of the planets by this correction, as it is of a variable and small amount.

The difference between the number of ASUS of the right ascension of the mean Sun [found at the end of the AHARGAṆA] and the number of ASUS equal to the number of minutes of the mean longitude of the Sun [found at the same time] is the difference between the true and mean AHARGAṆAS.* Multiply this difference by the daily motion of the planet and divide the product by the number of ASUS in a nycthemeron.† The result [thus found] in minutes is to be subtracted from the places of the planets, if the ASUS [of the right ascension of the mean Sun] fall short of the KALÁS or minutes [of the mean longitude of the Sun], otherwise the result is to be added to the places of the planets. Instead of the right ascension, if oblique ascension be taken [in this calculation] this UDAYÁNTARA correction which is to be applied to the places of the planets, includes also the CHARA correction or the correction for the ascensional difference.

Reason of the correction called the DES'A'NTARA.

23. The places of the planets which are found being rectified by this UDAYÁNTARA correction at the time of sun-rise at LANKÁ may be found, being applied with the DESÁNTARA correction, at the time of sun-rise at a given place. This DESÁNTARA correction is two-fold, one is east and west and the other

rise in equal periods. For this reason, the Sun does not come to the horizon at LANKA' at the end of the AHARGAṆA. Therefore the places of the planets determined by the mean AHARGAṆA, will not be at the sun-rise at LANKA'. Hence a correction is necessary to be applied to the places of the planets. This correction called UDAYÁNTARA has been first invented by BHÁSHARACHÁRYA who consequently abuses them who say that the places of the planets determined by the mean AHARGAṆA become at the time of the sun-rise at LANKÁ.—B. D.]

* The difference between the mean and true AHARGAṆAS is that part of the equation of time which is due to the obliquity by the ecliptic.—L. W.

† [This calculation is nothing else than the following simple proportion
If the number of ASUS in a nycthemeron
: daily motion of the planet
: : the difference between the true and mean AHARGAṆAS
give.—B. D.]

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is north and south. This north and south correction is called CHARA.

24. The line which passes from LANKÁ, UJJAYINÍ, KURUKSHETRA and other places to MERU (or the North Pole of the Earth) has been denominated the MADHYAREKHÁ mid-line of the Earth, by the Astronomers. The sun rises at any place east of this line before it rises to that line: and after it has risen on the line at places to its west. On this account, an amount of the correction which* is produced from the difference between the time of sun-rise at the mid-line and that at a given place, is subtractive or additive to the places of the planets, as the given place be east or west of the mid-line [in order to find the places of the planets at the time of sun-rise at the given place].

25. As the [small] circle which is described around MERU or North Pole of the Earth, at the distance in YOJANAS reckoned from MERU to given place and produced from co-latitude of the place [as mentioned in the verse 50th, Chapter III.] is called rectified circumference of the Earth (parallel of latitude) [at that place] therefore [to find this rectified circumference], the circumference of the Earth is multiplied by the sine of colatitude [of the given place] and divided by the radius.

End of 4th Chapter called MADHYA-GATI VASANA.

* This amount of correction is determined in the following manner.

The YOJANAS between the midline and the given place, in the parallel of latitude at that place, which is denominated SPASHTA-PARIDHI ara called, DES'A'NTARA YOJANAS of that place. Then by the proportion.

As the number of YOJANAS in the SPASHTA-PARIDHI : 60 GHATIKAS : : DESA'NTARA YOJANAS : the difference between the time of sun-rise at midline and that at a given place. This difference called DES'A'NTARA GHATIKA'S is the longitude in time east or west from LANKA'. Again

As 60 GHATIKA'S : daily motion of the planet : : DESANTA'RA GHATIKA'S : the amount of the correction required.

Or this amount can be found by using the proportion only once such as follows

As the number of YOJANAS in the SPASHTA-PARIDHI : daily motion of the planet : : DES'ÁNTARA YOJANAS : the same amount of the correction above found.—B. D.]

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CHAPTER V.

On the principles on which the Rules for finding the true places of the Planets are grounded.

On the canon of sines.

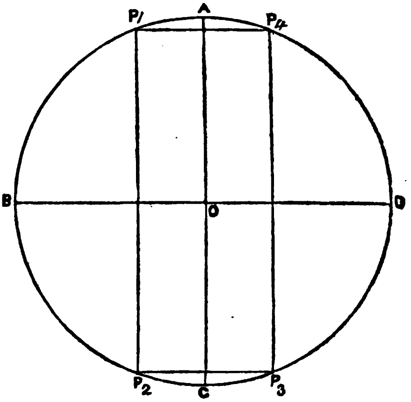
1. The planes of a Sphere are intersected by sines of BHUJA and KOṬI,* as a piece of cloth by upright and transverse threads. Before describing the spheric, I shall first explain the canon of sines.

2. Take any radius, and suppose it the hypothenuse (of a right-angled triangle). The sine of BHUJA is the base, and the sine of KOṬI is the square root of the difference of the squares of the radius and the base. The sines of degrees of BHUJA and KOṬI subtracted separately from the radius will be the versed sines of KOṬI and BHUJA (respectively).

[* The BHUJA of any given arc is that arc, less than 90°, the sine of which is equal to the sine of that given arc, (the consideration of the positiveness and negation of the sine is here neglected). For this reason, the BHUJA of that arc which terminates in the odd quadrants i. e. the 1st and 3rd is that part of the given arc which falls in the quadrant where it terminates, and the BHUJA of the arc which ends in the even quadrants, i. e. in the 2nd and 4th, is that arc which is wanted to complete the quadrant where the given arc is ended.

The KOṬI of any arc is the complement of the BHUJA of that arc.

Let the 4 quadrants of a circle A B C D be successively A B, B C, C D and D A, then the BHUJAS of the arcs A P_1, A B P_2, A C P_3, A D P_4 will be A P_1, C P_2, C P_3, A P_4 and the complements of these BHUJAS are the arcs B P_1, B P_2, D P_3, D P_4 respectively.—B. D.]



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3. The versed sine is like the arrow intersecting the bow and the string, or the arc and the sine.*

The square root of half the square of the radius is the sine of an arc of 45°. The co-sine of an arc of 45° is of the same length as the sine of that arc.

* These methods are grounded upon the following principles, written by BHA'SKARA'CHARYA, in the commentary VASANA'-BHA'SHYA.

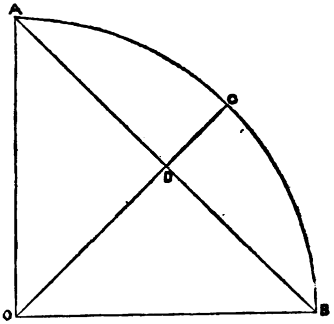
(1) Let the arc A B = 90° and A C = 45°

$\therefore$ A D ($= \frac{1}{2}$ A B) = sin. 45°; and let O A or O B = the radius (R) then $AB^2 = OA^2 + OB^2 = 2\,OA^2 = 2\,R^2$

$\therefore AB = \sqrt{2R^2}$

and $AD = \frac{1}{2}AB = \sqrt{\frac{R^2}{2}}$

or $\sin. 45° = \sqrt{\frac{R^2}{2}}$.



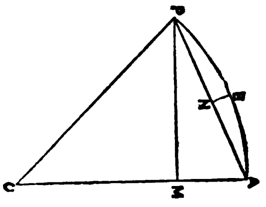
(2) It is evident and stated also in the LILA'VATI, that the side of a regular hexagon is equal to the radius of its circumscribing circle (i. e. ch. 60° = R). Hence, sin. 30° = $\frac{1}{2}$ R.

(3) Let A B be the half of a given arc A P, whose sine P M and versed sine A M are given. Then

$AP = \sqrt{PM^2 + AM^2}$,

and $\frac{1}{2}AP = AN = \sin. AB$

$\therefore \sin. AB = \frac{1}{2}\sqrt{PM^2 + AM^2}$



(4) The proof of the last method by Algebra

cos = R — versed sine

$\therefore \cos^2 = R^2 - 2R.v + v^2$

subtracting both sides from R^2,

$R^2 - \cos^2 = 2R.v - v^2$

or $\sin.^2 = 2R.v - v^2$

adding v^2 to both sides

$\sin.^2 + v^2 = 2R.v$

and $\frac{1}{4}(\sin.^2 + v^2) = \frac{1}{2}R.v$

extracting the square root,

$$\frac{1}{2}\sqrt{\sin.^2 + v^2} = \sqrt{\frac{1}{2}R.v}$$

but by the preceding method

$$\frac{1}{2}\sqrt{\sin.^2 + v^2} = \text{the sine of half the given arc};$$

$$\therefore \sin. \tfrac{1}{2}\,\text{arc} = \sqrt{\tfrac{1}{2}R.v}\text{.—B. D.]}$$

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4. Half the radius is the sine of an arc of 30°: The co-sine of an arc of 30° is the sine of an arc of 60°.

Half the root of the sum of the squares of the sine and versed sine of an arc, is the sine of half that arc.

5. Or, the sine of half that arc is the square-root of half the product of the radius and the versed sine.

The sines and co-sines of the halves of the arcs before found may thus be found to any extent.

6. Thus a Mathematician may find (in a quadrant of a circle) 3, 6, 12, 24 &c., sines to any required extent.*

Or, in a circle described with a given radius and divided into 360°, the required sines may be found by measuring their lengths in digits.

Reason of correction which is required to find the true from the mean place of a planet.

7.† As the centre of the circle of the constellation of the Zodiac coincides with the centre of the Earth;

* [When, 24 sines are to be determined in a quadrant of a circle, the 3 sines, i. e. 12th, 8th and 16th, can be easily found by the method here given for finding the sines of 45°, 30°, and the complement of 30°, i. e. 60°. Then by means of these three sines, the rest can be found by the method for finding the sine of half an arc, as follows. From the 8th sine, the 4th and the co-sine of the 4th i. e., the 20th sine, can be determined. Again, from the 4th, the 2nd and 22nd, and from the 2nd, the 1st and 23rd, can be found. In like manner, the 10th 14th, 5th, 19th, 7th, 17th, 11th, and 13th, can also be found from the 8th sine. From the 12th again, the 6th, 18th, 3rd, 21st, 9th and 15th can be determined, and the radius is the 24th sine. Thus all the 24 sines are found. Several other methods for finding the sines will be given in the sequel.—B. D.]

[† BHA'SKARA'CHA'RYA maintains that the Earth is in the centre of the Universe, and the Sun, Moon and the five minor planets, Mars, Mercury, &c. revolve round the Earth in circular orbits, the centres of which do not coincide with that of the Earth, with uniform motion. The circle in which a planet revolves is called PRATIVṚITTA, or excentric circle, and a circle of the same size which is supposed to have the same centre with that of the Earth, is called KAKSHA'VṚITTA or concentric circle. In the circle, the planet appears to revolve with unequal motion, though it revolves in the excentric with equal motion. The place where the planet revolving in the excentric appears in the concentric is its true place and to find this, astronomers apply a correction called MANDA-PHALA (1st equation of the centre) to the mean place of the planet. A mean planet thus corrected is called MANDA-SPASHṬA, the circle in which it revolves MANDA-PRATÍVṚITTA (1st excentric) and its farthest point from the centre of the concentric, MANDOCHCH (1st higher Apsis). As the mean places of the Sun and Moon when corrected by 1st equation become true at the centre of the Earth, this correction alone is sufficient for them. But the five minor planets, Mars, Mercury, &c. when corrected by the 1st equation are not true at the centre of the Earth but at another place. For this reason, astronomers having assumed

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and the centre of the circle in which the planet revolves does not coincide with the centre of the Earth: the spectator, therefore, on the Earth does not find the planet in its mean place in the Zodiac. Hence Astronomers apply the correction called BHUJA PHALA to the mean place of the planet [to get the true place].

Mode of illustration of the above fact.

8. On the northern side of a wall running due east and west, let the teacher draw a diagram illustrative of the fact for the satisfaction of his pupils.

A verse to encourage those who may be disposed to despond in consequence of the difficulties of the science.

9. But this science is of divine origin, revealing facts not cognizable by the senses. Springing from the

the concentric circle as second excentric of these five planets, take another circle of the same size and of the same centre with the Earth as concentric, and in order to find the place where the planet revolving in the 2nd excentric appears, in this concentric, they apply a correction called S'ÍGHRA-PHALA, or 2nd equation of the centre, to the mean place corrected by the 1st equation. The MANDA-SPASHTA planet, when corrected by the 2nd equation is called S'PASHTA, or true planet, the 2nd excentric, S'ÍGHRA-PRATIVRITTA, and its farthest point from the centre of the Earth, S'ÍGHROCHCH the 2nd higher Apsis.

If a man wishes to draw a diagram of the arrangement of the planets according to what we have briefly stated here, he should first describe the excentric circle, and through this excentric the concentric, and then he may determine the place of the MANDA-SPASHTA planet in the concentric thus described. Again, having assumed the concentric as 2nd excentric and described the concentric through this 2nd excentric, he may find the place of the true planet. This is the proper way of drawing the diagram, but astronomers commonly, having first described the concentric, and, through it, the excentric, find the corrected mean place of the planet in the concentric. After this, having described the 2nd excentric through the same concentric, they find the true place in the concentric, through the corrected mean place in the same. These two modes of constructing the diagram differ from each other only in the respect, that in the former, the concentric is drawn through the excentric circle, and in the latter, the excentric is drawn through the concentric, but this can easily be understood that both of these modes are equivalent and produce the same result.

In order to find the 1st and 2nd equations through a different theory, astronomers assume that the centre of a small circle called NÍCHOCHCHA-VRITTA or epicycle, revolves in the concentric circle with the mean motion of the planet and the planet revolves in the epicycle with a reverse motion equal to the mean motion. BHA'SKARA'CHA'RYA, himself will show in the sequel that the motion of the planet is the same in both these theories of excentrics and epicycles.

It is to be observed here that, in the case of the planets Mars, Jupiter and Saturn, the motion in the excentric is in fact their proper revolution, in their orbits, and the revolution of their S'ÍGHROCHCHA, or quick apogée, corresponds to a revolution of the Sun. But in the case of the planets Mercury and Venus, the revolution in the excentric is performed in the same time with the Sun, and the revolutions of their S'ÍGHROCHCHAS are in fact their proper revolutions in their orbits.—B. D.]

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supreme BRAHMA himself it was brought down to the Earth by VASISHṬHA and other holy Sages in regular succession; though it was deemed of too secret a character to be divulged to men or to the vulgar. Hence, this is not to be communicated to those who revile its revelations, nor to ungrateful, evil-disposed and bad men: nor to men who take up their residence with its professors for but a short time. Those professors of this science who transgress these limitations imposed by holy Sages, will incur a loss of religious merit, and shorten their days on Earth.

Construction of a diagram to illustrate the excentric theory.

10. In the first place then, describe a circle with the compass opened to the length of the radius (3438). This is called the KAKSHA'VṚITTA, or concentric circle; at the centre of the circle draw a small sphere of the Earth with a radius equal to $\frac{1}{15}$th* of the mean daily motion of the planet.

11. In this concentric circle, having marked it with 360°, find the place of the higher apsis and that of the planet, counting from the 1st point of stellar Aries; then draw a (perpendicular) diameter passing through the centre of the Earth and the higher apsis (which is called UCHCHA-REKHÁ, the line of the apsides) and draw another transverse diameter [perpendicular to the first] also passing through the centre.

12. On this line which passes to the highest apsis from the centre of the Earth, take a point at a distance from the Earth's centre equal to the excentricity or the sine of the greatest equation of the centre, and with that point as centre and the radius [equal to the radius of the concentric], describe the PRATIVṚITTA or excentric circle; the UCHCHA-REKHA' answers the like purpose also in this circle, but make the transverse diameter different in it.

* All the Hindu Astronomers seem to coincide in thinking that the horizontal parallax PARAMA-LAMBANA of all the planets amounts to a quantity equal to $\frac{1}{15}$th of their daily motion.—L. W.

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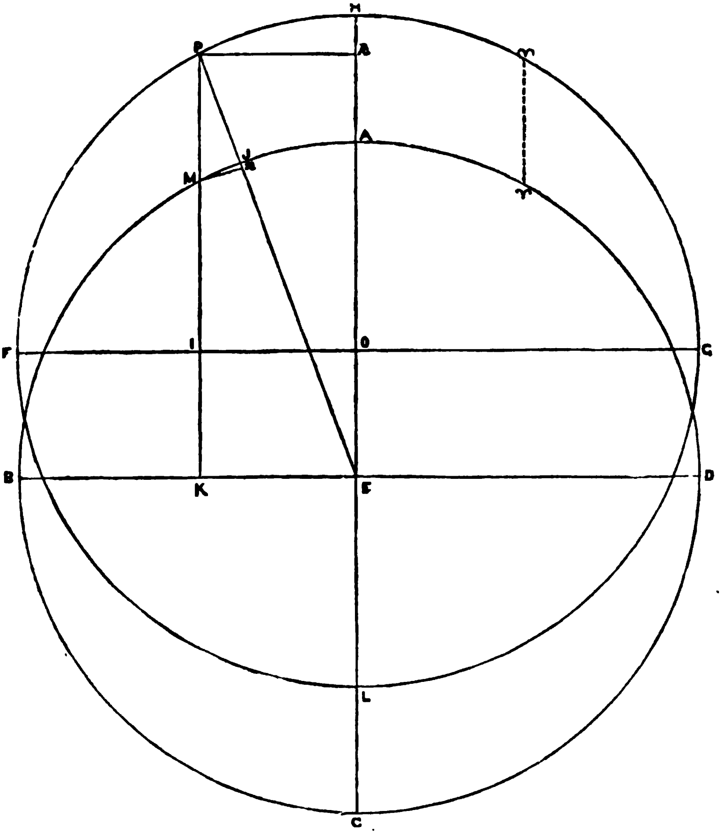
13 and 14.* Where the UCHCHA-REKHA' perpendicular diameter (when produced) cuts the excentric circle, that is the

* Fig. 1.



[In fig. 1st let E be the centre of the concentric circle A B C D, ♈ the place of the stellar Aries, A that of the higher apsis, and M that of the mean planet in it: then E A will be the UCHCHA-REKHA (the line of the apsides). Again let E O be the excentricity and H F L G the excentric which has O for its centre; then H, ♈ P, will be the places of the higher apsis, the stellar Aries and the planet respectively in it. Hence H P will be the KENDRA; P K the sine of the KENDRA; P I the co-sine of the KENDRA.

The KENDRA which is more than 9 signs and less than 3 is called MRIGADI (i. e. that which terminates in the six signs beginning with Capricornus) and that which is above 3 and less than 9 is called KARKYADI (i. e. that which ends in the six signs beginning with Cancer).

Thus (Fig. 1) that which terminates in G H F is MRIGADI KENDRA, and that which ends in F L G is KARKYA'DI.—B. D.]

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place of the higher apsis in it also. From this mark the first stellar Aries, at the distance in degree of the higher apsis in antecedentia: the place of the planet must be then fixed counting the degree from the mark of the 1st Aries in the usual order.

The distance between the higher apsis and the planet is called the KENDRA.* The right line let fall from the planet on the UCHCHA-REKHÁ is the sine of BHUJA of the KENDRA. The right line falling from the planet on the transverse diameter is the cosine of the KENDRA, it is upright and the sine of BHUJA is a transverse line.

The principle on which the rule for finding the amount of equation of centre is based.

15. As the distance between the diameters of the two circles is equal to the excentricity and the co-sine of the KENDRA is above and below the excentricity when the KENDRA is MRIGÁDI and KARKYÁDI (respectively).†

* The word KENDRA or centre is evidently derived from the Greek word *κεντρον* and means the true centre of the planet.—L. W.

† [In (Fig. 1) P K is the SPHUṬA KOṬI and P E the KARṆA (the hypothenuse) which cuts the concentric at T. Hence the point T will be the apparent place of the planet and T M the equation of the centre.

This equation can be determined as follows.

Draw M *n* perpendicular to E T, it will be the sine of the equation and the triangle P M *n* will be similar to the triangle P E K.

$$\therefore PE : EK = PM : Mn;$$

$$\text{hence } Mn = \frac{PM . EK}{PE} = \text{sine of the equation};$$

$$= \frac{EO . EK}{PE}, \text{ for } PM = IK = EO$$

Now, let k = KENDRA, a = the distance between the centres of the two circles excentric and concentric, x = sine of the equation, and h = hypothenuse: then the SPHUTA KOṬI = cos. $k \pm a$, according as the KENDRA is MRIGADI or KARKYADI, and $h = \sqrt{\text{sin.}^2 k \pm (\text{cos. } k \pm a)^2}$

hence by substitution

$$x = \frac{a . \text{sin. } k}{h} = \frac{a . \text{sin. } k}{\sqrt{\text{sin.}^2 k + (\text{cos. } k \pm a)^2}}$$

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16 and 17. Therefore the sum or difference of the co-sine and excentricity (respectively) is here the SPHUṬA KOṬI (i. e. the upright side of a right-angled triangle from the place of the planet in the excentric to the transverse diameter in the concentric,) the sine of the BHUJA [of the KENDRA] is the BHUJA (the base) and the square-root of the sum of the squares of the SPHUṬA KOṬI and BHUJA is called KARṆA, hypothenuse. This hypothenuse is the distance between the Earth's centre and the planet's place in the excentric circle.

The planet will be observed in that point of the concentric cut by the hypothenuse.

The equation of the centre is the distance between the mean and apparent places of the planet: when the mean place is more advanced than the apparent place then the equation thus found is subtractive; when it is behind the true place, the equation is additive.*

The reason for assuming the MAND-SPASHṬA planet as a mean in finding the 2nd equation.

18. The mean planet moves in its MANDA-PRATIVṚITTA (first excentric); the MANDA-SPASHṬA planet (i. e. whose mean place is rectified by the first equation) moves in its S'IGHRA-PRATIVṚITTA (second excentric). The MANDA-SPASHṬA

It also follows from this that, when cos. k is equal to a in the KARKYADI KENDRA, then h will be equal to sin. k, otherwise h will always be greater than sin. k and consequently x will be less than a. Hence, when h is equal to sin k, x will then be greatest and equal to a, i. e. the equation of the centre will be greatest when the hypothenuse is equal to the sine of the KENDRA, or when the planet reaches the point in the excentric cut by the transverse line in the concentric. Therefore, the centre of the excentric is marked at the distance equal to the excentricity from the centre of the concentric (as stated in the V 12th.)—B. D.]

* [Thus, the mean planet, corrected by the 1st equation, becomes MANDA-SPASHṬA and this process is called the MANDA process. After this, the MANDA-SPASHṬA when rectified by the SI'GHRA PHALA, or 2nd equation, is the SPASHṬA planet, and this 2nd process is termed the S'IGHRA process. Both of these processes, MANDA-SPASHṬA and SPASHṬA are reckoned in the VIMAṆḌALA or the orbit of the planet as hinted at by BHASKARACHARYA in the commentary called VASANA-BHASHYA in the sequel. These places are assumed for the ecliptic also without applying any correction to them, because the correction required is very small.—B. D.]

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is therefore here assumed as the mean planet in the second process (i. e. in finding the second equation).*

The reason for the invention of the higher apsis.

19. The place in the concentric in which the revolving planet in its own excentric is seen by observers is its true place. To find the distance between the true and mean places of the planet, the higher apsis has been inserted by former Astronomers.

20. That point of the excentric which is most distant from the Earth has been denominated the higher apsis (or UCHCHA): that point is not fixed but moves; a motion of the higher apsis has therefore been established by those conversant with the science.

21. The lower apsis is at a distance of six signs from the higher apsis: when the planet is in either its higher or lower apsis, then its true place coincides with its mean place, because the line of the hypothenuse falls on the mean place of the planet in the concentric.

22. As the planet when in the higher apsis is at its greatest distance from the Earth, and when in the lower apsis at its least distance, therefore its disc appears small and large accordingly. In like manner, its disc appears small and large accordingly as the planet is near to and remote from the Sun.

The cause of variation of apparent size of planet's disc.

23. To prevent the student from becoming confused, I have separately explained the proof of finding the equation by the PRATIVRITTA BHANGI of the diagram of the excentric. I shall now proceed to explain the same proof in a different manner by the diagram of a NÍCHOCHCHA-VRITTA (epicycle).

* [For this reason, having assumed the MANDA-SPASHṬA planet for the mean, which MANDA-SPASHṬA can be determined in the concentric by describing the excentric circle &c. through the mean planet and MANDOCHCHA, make the place of the stellar Aries from the MANDA-SPASHṬA place in the reverse order of the signs and then determine the place of the S'ÍGHROCHCHA in the order of the signs. Through the places of the stellar Aries and S'ÍGHROCHCHA describe the 2nd excentric circle &c. in the way mentioned before, and then find the place of the true planet in the concentric.—B. D.]

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Construction of Diagram to illustrate the theory of epicycle.

24. Taking the mean place of the planet in the concentric as the centre, with a radius equal to the excentricity of the planet, draw a circle. This is called NÍCHOCHCHA VRITTA or epicycle. Then draw a line from the centre of the Earth passing through the mean place of the planet [to the circumference of the epicycle].

25. That place in the epicycle most distant from the centre of the Earth, cut by the line [joining the centre of the Earth and mean place of the planet] is supposed to be the place of the higher apsis: and the point in the epycicle nearest to the Earth's centre, the lower apsis. In the epicycle draw a transverse line passing through the centre of it [and at right-angles to the above-mentioned line which is called here UCHCHA-REKHÁ].

26. As the mean planet revolves with its KENDRA-GATI (the motion from its higher apsis) in the 1st and 2nd epicycle marked with the 12 signs and 360 degrees towards the reverse signs, and according to the order of the signs respectively from its higher apsis.

27. Mark off therefore the places of the first and second KENDRAS or distances from their respective higher apsides in the manner directed in the last verse: the planet must be fixed at those points. [Here also] The (perpendicular) line from the planet to the UCHCHA-REKHÁ is the sine of the BHUJA of the KENDRA: and from the planet on the transverse line is the cosine [of the KENDRA].* *(See note next page.)*

To find the hypothenuse and the equation of centre.

28 and 29. The BHUJA PHALA and KOṬI PHALA of the KENDRA which are found [in the GANITÁDHYÁYA] are sine and cosine in the epicycle. As the KOṬI PHALA is above the radius (of the concentric) in MRIGÁDI KENDRA and within the radius in KARKYÁDI-KENDRA, the sum and difference, therefore, of the KOṬI PHALA and the radius is here the SPHUTA-KOṬI (upright line), the BHUJA PHALA is the BHUJA (the base) and the KARṆA hypothenuse (to complete

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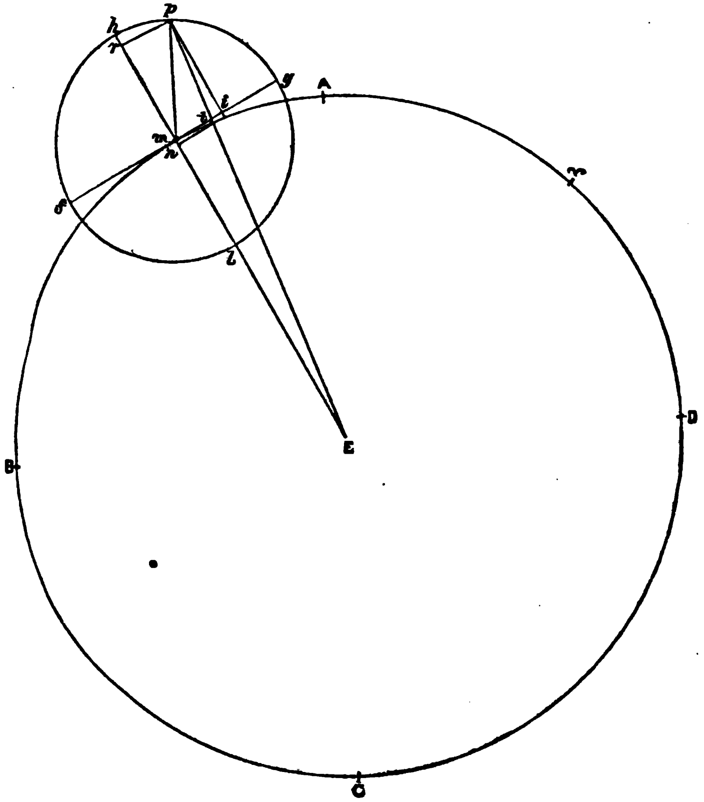
the right-angled triangle) is the line intercepted between the centre of the Earth and the planet. The equation of the centre is here the arc [of the concentric] intercepted between

* **Note on verses from 24 to 27.**



[In fig. 2, let A B C D be the concentric, ♈ the place of the stellar Aries, E the centre of the Earth, M the mean place of the planet in the concentric, *h f l g*, the Epicycle, *h* the place of the higher apsis in it, E *h* the UCHCHA-REKHÁ' *l* the place of the lower Apsis, P that of the planet, *h* P the KENDRA, P *k* the sine of the KENDRA and P *i* the cosine of it.

The sine and co-sine of the KENDRA in the excentric, reduced to their dimensions in the epicycle in parts of the radius of the concentric, are named BHUJA-PHALA and KOṬI-PHALA respectively in the GAṆITÁDHYÁYA. That is

As the radius or 360° of the concentric
: the sine and cosine of the KENDRA in the excentric
: : excentricity or the periphery of the epicycle
: BHUJA-PHALA and KOṬI-PHALA respectively.

Therefore the BHUJA-PHALA and KOTI-PHALA must be equal to the sine and cosine of the KENDRA in the epicycle.—B. D.]

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the mean place of the planet and the point cut by the hypothenuse. The equation thus found is to be added or subtracted as was before explained.*

Construction of the mixed diagrams of the excentric and epicycle.

30. The planet appears to move forward from MANDOCHCHA, or 1st higher apsis, in the excentric circle with its KENDRA-GAṬI (the motion from its MANDOCHCHA) and in the order of the signs and to the East: From its SI'GHROCHCHA, 2nd higher apsis, it moves in antecedentia or reversely, as it is thrown backwards.

31. When the epicycle however is used, the reverse of this takes place, the planet moving in antecedentia from its 1st higher apsis and in the order of the signs from its 2nd higher apsis. Now as the actual motion in both cases is the same, while the appearances are thus diametrically opposed, it must be admitted therefore that these expedients are the mere inventions of wise astronomers to ascertain the amount of equation.

* In (Fig 2) E k is the SPHUṬA-KOṬI, P E the hypothenuse, T the apparent place of the planet in the concentric and T M the equation of the centre. This equation can also be found by the theory of the epicycle in the following manner.

Draw T n perpendicular to E M, then T n will be the sine of the equation; let it be denoted by x, the KENDRA in the excentric by k, the excentricity by a, and the hypothenuse by h: then

$$R : \sin k = a : Pk \text{ the BHUJA-PHALA}$$

$$\therefore \text{ the BHUJA-PHALA} = \frac{a \sin k}{R},$$

Now, the triangles E T n and E P k are similar to each other

$$\therefore EP : Pk = ET : Tn,$$
$$\text{or } h : Pk = R : x$$

$$\therefore x = \frac{Pk \times R}{h};$$

that is, the BHUJA-PHALA multiplied by the radius and divided by the hypothenuse is equal to the sine of the equation.

$$\text{But } Pk = \frac{a \sin k}{R};$$

$\therefore$ by substitution

$$x = \frac{a \sin k}{R} \times \frac{R}{h} = \frac{a \sin k}{h},$$ the sine of the equation as found before by the theory of the excentric in the note on the verses 15, 16 and 17.—B. D.]

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32. If the diagrams (of the excentric and epicycle) be drawn unitedly, and the place of the planet be marked off in the manner before explained, then the planet will necessarily be in the point of the intersection of the excentric by the epicycle.

33. [In illustration of these opposite motions, examine an oil-man's screw-press.] As in the oil-man's press, the wooden press (moving in the direction in which the bullock fastened to it goes) moves (also itself) in the opposite direction to that in which the bullock goes, thus the motion of the planet, though it moves in the excentric circle, appears in antecedentia in the epicycle.

34. As the centre of the 1st epicycle is in the concentric, let the planet therefore move in the concentric with its mean motion: In the concentric [at that point cut by the first hypothenuse] is the centre of the SI'GHRA NÍCHOCHCHA, VṚITTA or of the 2nd epicycle: In the second or S'IGHRA epicycle is found the true place of the planet.

Explains why the 5 minor planets require both the 1st and 2nd equations to their true places.

35. The first process, or process of finding the 1st equation, is used in the first place, in order to ascertain the position of the centre of the SÍGHRA NÍCHOCHCHA VṚITTA or of the 2nd epicycle, and the 2nd process, or the process of the 2nd equation, to ascertain the actual place of the planet. As these two processes are mutually dependent, it on this account becomes necessary to have recourse to the repetition of these two processes.

36 and 37. Some say that the hypothenuse is not used in the 1st process, because the difference (in the two modes of computation) is inconsiderable, but others maintain that since in this process the periphery of the first epicycle being multiplied by the hypothenuse and divided by the radius becomes true, and that, if the hypothenuse then be used, the result is the same as it was before, therefore the hypothenuse is

Explains reason of omission of hypothenuse in the MANDA process.

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not employed. No objection is to be made why this is not the case in the 2nd process, because the proofs of finding the equation are different here.*

38. As no observer on the surface of the Earth sees the planet moving in the excentric, deflected from his zenith, in that place of the concentric, where an observer situated at the centre of the Earth observes it in the eastern or western hemisphere, and at noon both observers see it in the same place, therefore the correction called NATAKARMA is declared (by astronomers). The proof of this is the same as in finding the parallax.†

Reason of NATAKARMA.

* [The BHUJA-PHALA, determined by means of the sine of the first KENDRA of the planet (i. e. by multiplying it by the periphery of the 1st epicycle and dividing it by 360°) has been taken for the sine of the 1st equation of the centre: and what we have shown in the note on the V. 28 and 29, that the BHUJA-PHALA, when multiplied by the radius and divided by the hypothenuse, becomes the sine of the equation may be understood only for finding the 2nd equation of the five minor planets and not for determining the 1st equation.

Some say that the omission of the hypothenuse in the 1st process has no other ground but the very inconsiderable difference of the result. But BRAHMAGUPTA maintains that the periphery of the 1st epicycle, varies according to the hypothenuse; that is, their ratio is always the same, and the periphery of the 1st epicycle, mentioned in the GAṆITÁDHYÁYA, is found at the instant when the hypothenuse is equal to the radius. For this reason, it is necessary at first to find the true periphery through the hypothenuse and then determine the 1st equation. But, he declares that by so doing; also the sine of the equation becomes equal to the BHUJA-PHALA as follows.

As R : 1st periphery = the hypothenuse : the true periphery

$\therefore$ the true periphery $= \dfrac{P \times h}{R}$, and consequently the BHUJA-PHALA in the true epicycle $= \dfrac{P \times h}{R} \times \dfrac{\sin k}{360°}$;

$\therefore$ the sine of the 1st equation $= \dfrac{P \times h}{R} \times \dfrac{\sin k}{360°} \times \dfrac{R}{h}$ and abridging $= \dfrac{P \cdot \sin k}{360°}$ which is equal to the BHUJA-PHALA. Hence the hypothenuse is not used in the 1st process.

BRAHMAGUPTA's opinion is much approved of by BHA'SKARA'CHA'RYA.—B. D.]

† But this is not the case, because the NATAKARM which BHA'SKARA'CHA'RYA has stated in the GAṆITÁDHYÁYA has no connection with the fact stated in this S'LOKA and therefore many say that this S'LOKA does not belong to the text.—B. D.]

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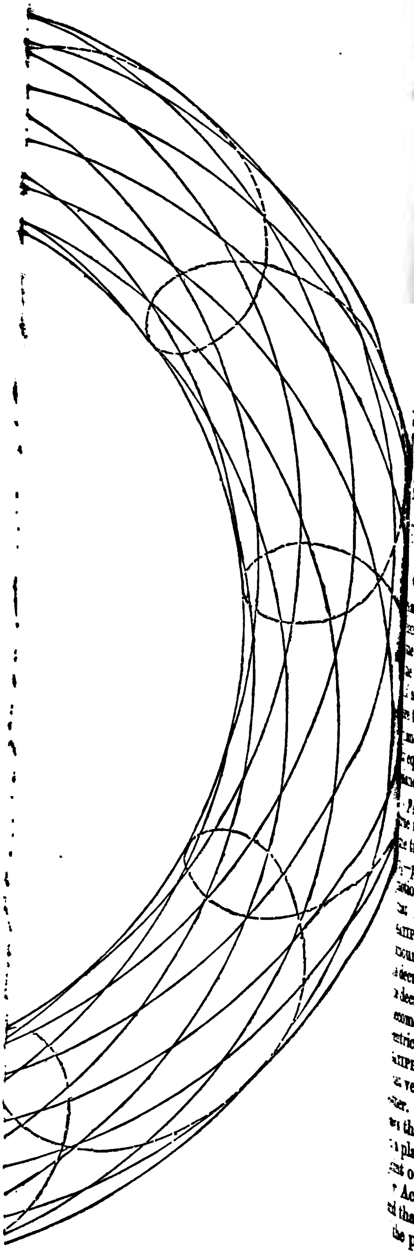

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39. The mean motion of a planet is also its true motion when the planet reaches that point in the excentric cut by the transverse diameter which passes through the centre of the concentric: and it is when the planet is at that point that the amount of equation is at its maximum. [LALLA has erroneously asserted that the mean and true motions coincide at the point where the concentric is cut by its excentric.]*

Explains where the mean and true motions of all the planets coincide.

40. Having made the excentric and other circles of thin pieces of bamboo in the manner explained before, and having changed the marks of the places of the planet and its S'ÍGHROCHCHA 2nd higher apsis with their daily motions, an astronomer may quickly show the retrogressions, &c.†

Manner of observing the retrogression &c. of Planets.

* The ancient astonomers LALLA, S'RIPATI &c. say that the true motion of a planet equals to its mean motion when it reaches the point of intersection of the concentric and excentric. But BHA'SKARA'CHARYA denying this, says, that when the planet reaches the point when the transverse axis of the concentric cuts the excentric and when the amount of equation is a maximum, the true motion of a planet becomes equal to its mean motion. For, suppose, p_1, p_2, p_3, &c., are the mean places of a planet found on successive days at sun-rise when the planet proceeded from its higher or lower apsis and e_1, e_2, e_3, &c. are the amounts of equation, then $p_1 \pm e_1$, $p_2 \pm e_2$, $p_3 \pm e_3$, &c. will be the true places of the planct,
$\therefore p_2 - p_1 \pm (e_2 - e_1), p_3 - p_2 \pm (e_3 - e_2), p_4 - p_3 \pm (e_4 - e_3)$, &c. will be the true motions of the planet on successive days. Now, as the difference between the true and mean motions is called the GATIPHALA, by cancelling therefore, $p_2 - p_1$ $p_3, - p_2$, &c. the parts of the true motions which are equal to the mean motion, the remaining parts $e_2 - e_1$, $e_3 - e_2$ &c. will evidently be the GATIPHALAS that is the differences between two successive amounts of equation arè the GATIPHALAS. Thus, it is plain that the GATIPHALA entirely depends upon the amount of equation, but as the amount of equation increases, so the GATIPHALA is decreased and therefore when it is a maximum, the GATIPHALA will indifintely be decreased i. e. will be equal to nothing. Now as the amount of equation becomes a maximum in that place where the transverse diameter of the concentric circle cuts the excentric, (see the note on verses 15, 16 and 17) the GATIPHALA, therefore becomes equal to nothing at the same place, that is, in that very place, the true motion and mean motions of a planet are equal to each other. Having thus shown a proof of his own assertion, BHÁSKARA'CHA'RYA says that what the ancient astronomers stated, that the true and mean motions of a planet are eqnal to each other when the planet comes in the intersection point of the concentric and excentric circles, is entirely ungrounded.—B. D.]

† According to the method above mentioned, if the place of the higher apsis and that of the planet be changed, and the planet's place be marked, the motion of the planet will be in a path like the dotted line as shown in the diagram.

See Diagram facing this page.

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41. The word KENDRA (or κεντρον) means the centre of a circle: it is on that account applied to the distance between the planet and higher apsis, for the centre of the NICHOCHCHA-VṚITTA or epicycle, is always at the distance of the planet from the place of the higher apsis.

The reason of the invention of the appellation of KENDRA.

42. The circumference in YOJANAS of the planet's orbit being multiplied by the S'ÍGHRA-KARṆA (or 2nd hypothenuse), and divided by the radius (3438) is SPHUTA-KAKSHÁ (corrected orbit). The planet is (that moment) being carried [round the earth] by the PRAVAHA wind, and moves at a distance equal to half the diameter of the SPHUTA-KAKSHÁ from the earth's centre.

SPHUṬA-KAKSHA or corrected orbit.

43. When the sun's MANDA-PHALA i. e. the equation of the centre is subtractive, the apparent or real time of sun-rise takes place before the time of mean sun-rise: when the equation of the centre is additive, the real is after the mean sun-rise, on that account the amount of that correction arising from the sun's MANDA-PHALA converted into ASUS* of time has been properly declared to be subtractive or additive.

Reason of BUJA'NTARA correction.

44. Those who have wits as sharp as the sharp point of the inmost blade of the DORBHA or DARBHA grass, find the subject above explained by diagrams, a matter of no difficulty whatever: but men of weak and blunt understanding find this subject as heavy and immovable as the high mountain† that has been shorn of its wings by the thunderbolt of Indra.

End of Chapter V. on the principles on which the rules for finding the true places of the planets are grounded.

It is to be observed here that when the planet comes to the places *a*, *a* &c. in the dotted line, it is then at its higher apsis, when it comes to the places *c*, *c* and *c*, it is at its lower, and when it comes to *b*, *b* &c. it appears, stationary: and when it is moving in the upper arc *b a b*, its motion being direct appears quicker, and when in the lower arc *b c b*, its retrograde motion is seen.—B. D.]

* [These ASUS are equivalent to that part of the equation of time, which is due to the unequal motion of the sun on the ecliptic.—B. D.]

† Mountains are said by Hindu theologians to have originally had wings.

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CHAPTER VI.

Called GOLABANDHA, *on the construction of an Armillary Sphere.*

1. Let a mathematician, who is as skilful in mechanics as in his knowledge of the sphere, construct an armillary sphere with circles made of polished pieces of straight bamboo; and marked with the number of degrees in the circle.

2. In the first place, let him mark a straight and cylindrical DHRUVA-YASHTI, or polar axis, of any excellent wood he pleases: then let him place loosely in the middle of it a small sphere to represent the earth [so that the axis may move freely through it]. Let him then firmly secure the spheres beyond it of the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn and the fixed stars: Beyond them let him place two spheres called KHAGOLA and DṚIGGOLA unconnected with each other, and fastened to the hollow cylinders [in which the axis is to be inserted].*

[Description in detail of the fact above alluded to.]

The prime vertical, the meridian and the KOṆAVRIT-TAS.

3. Fix vertically the four circles and another circle called horizon transversely in the middle of them, so that one of those vertical circles called SAMAMAṆḌALA, prime vertical, may pass through the east and west points of the horizon, the other called YÁMYOTTARA-VRÍTTA, meridian the

* The sphere of the fixed stars which is mentioned here is called the BHAGOLA starry sphere. This BHAGOLA is assumed for all the planets, instead of fixing a separate sphere for each planet. This sphere consists of the circles ecliptic, equinoctial, diurnal circles, &c. which are moveable. For this reason, this sphere is to be firmly fixed to the polar axis, so that it may move freely by moving the axis. Beyond this sphere, the KHAGOLA celestial sphere which consists of the prime vertical, meridian, horizon, &c. which remain fixed in a given latitude is to be attached to the hollow cylinders. Having thus separately fixed these two spheres, astronomers attach, beyond these, a third sphere in which the circles forming both the spheres KHAGOLA and BHAGOLA are mixed together. For this reason the latter is called DṚIGGOLA the double sphere. And as the spherical fingers are well seen by mixing together the two spheres KHAGOLA and BHAGOLA, the third sphere which is the mixture of the two spheres, is separately attached.—B. D.]

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north and south points, and the remaining two called KOṆA-VṚITTAS the N. E. and S. W. and N. W. and S. E. points.

The UNMANḌALA or six o'clock line.

4. Then fix a circle passing through the points of the horizon intersected by the prime vertical, and passing also through the south and north poles at a distance below and above the horizon equal to the latitude of the place. This is called the UNMANḌALA, or six o'clock line, and is necessary to illustrate the increase and decrease in the length of the days and nights.*

The equinoctial.

5. The equinoctial (called NÁḌÍ-VALAYA), marked with 60 ghaṭis, should be placed so as to pass through the east and west points of the horizon, and also to pass over the meridian at a distance south from the zenith equal to the latitude, and at a distance north of the nadir also equal to the latitude of the place [for which the sphere is constructed].

Azimuth or vertical circle.

6. Let the azimuth or vertical circle be next attached within the other circles, fixed by a pair of nails at the zenith and nadir, so as to revolve freely on them: [It should be smaller than the other circles so as to revolve within them]. It should be capable of being placed so as to cover the planet, wherever it may happen to be.

7. Only one azimuth circle may be used for all the planets; or else eight azimuth circles may be made, viz. one for each of the 7 planets and the 8th for the nonagesimal point. The azimuth circle for the nonagesimal point is called the DṚIK-SHEPA-VṚITTA.

* The circle of declination or the hour circle passing through the east and west points of the horizon is called UNMANḌALA in Sanskrit; but I am not acquainted with any corresponding term in English. In the treatise on astronomy in the Encyclopædia Metropolitana the prime vertical is named the six o'clock line. This term (six o'clock line) should, I think, be applied to the UNMANḌALA, because it is always six o'clock when the sun arrives at this circle, the UNMANḌALA. The prime vertical or the SAMA-MANDALA of the Sanskrit cannot, with propriety, be called the six o'clock line; because it is only twice a year that it is six o'clock when the sun is at this circle, the prime vertical.—B. D.]

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8. Let two hollow cylinders project beyond the two poles north and south of the KHAGOLA celestial sphere, and on these cylinders let the skilful astronomer place the DṚIGGOLA double sphere as follows.

The DṚIGGOLA.

9. When the system of the KHAGOLA, celestial sphere, is mixed with the ecliptic, and all the other circles forming the BHAGOLA (which will be presently shown) it is then called DṚIGGOLA, double sphere. As in this the figures formed by the circles of the two spheres KHAGOLA and BHAGOLA are seen, it is therefore called DṚIGGOLA double sphere.*

THE BHAGOLA.

10. Let two circles be firmly fixed on the axis of the poles answering to the meridian and horizon (of the KHAGOLA); they are called the ÁDHÁRA-VṚITTAS, or circles of support: Let the equinoctial circle also be fixed on them marked with 60 ghaṭis like the prime vertical (of the KHAGOLA).

11. Make the ecliptic (of the same size) and mark it with 12 signs; in this the Sun moves: and also in it revolves the Earth's shadow at a distance of 6 signs from the Sun. The KRÁNṬI-PÁTA or vernal equinox, moves in it contrary to the order of the signs: The SPASHṬA-PÁTAS [of the other planets] have a like motion: the places of these should be marked in it.†

The Ecliptic.

* See the note on 2 Verse.

† [The Sun revolves in the ecliptic, but the planets, Moon, Mars, &c. do not revolve in that circle, and the planes of their orbits are inclined to that of the ecliptic. Of the two points where the planetary orbit cuts the plane of the ecliptic, that in which the planet in its revolution rises to the north of the ecliptic is called its PA'TA or ascending node (it is usually called the mean PA'TA) and that which is at the distance of six signs from the former is called its SASHADBHA PA'TA or descending node. The PA'TA of the Moon lies in its concentric, because the plane of its orbit passes through the centre of the concentric, i. e. through the centre of the Earth; but the PA'TAS of the other planets are in their second excentric, because the planes of their orbits pass through the centres of their 2nd excentrics, which centres lie in the plane of the ecliptic. When the planet is at any other place than its nodes, the distance between it and the plane of the ecliptic is called its north or south latitude as the planet is north or south of the ecliptic. When the planet is at the distance of 3 signs forward or backward from its PA'TA, it is then at the greatest distance north or south from the ecliptic: This distance is its greatest latitude. Thus,

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12. Let the ecliptic be fixed on the equinoctial in the point of vernal equinox KRÁNṬI-PÁTA and in a point (autumnal equinox) 6 signs from that: it should be so placed that the point of it, distant 3 signs eastward from the vernal equinox, shall be 24° north of the equinoctial, and the 3 signs westward shall be at the same distance south from the equinoctial.

Planet's orbit.

13. Divide a circle called KSHEPA-VṚITTA representing the orbit of a planet into 12 signs and mark in it the places of the SPASHTA-PÁTAS, rectified nodes, as has been before prescribed [for the ecliptic]. Then this circle should be so placed in connection with the ecliptic as it has been placed in connection with the equinoctial.

14. The ecliptic and the KSHEPA-VṚITTA should be so placed that the latter may intersect the former at the [rectified] ascending and descending nodes, and pass through points distant 3 signs from the ascending node east and west at a distance from the ecliptic north and south equal to the rectified greatest latitude of the planet [for the time].

15. The greatest (mean) latitudes of the planets being multiplied by the radius and divided by the SÍGHRA-KARṆA

the latitude of the planet begins from its PA'TA and becomes extreme at the distance of 3 signs from it, therefore, in order to find the latitude, it is necessary to know the distance between the planet and its PA'TA. This distance is equal to the sum of the places of the planet and its PA'TA, because all PA'TAS move in antecedentia from the stellar aries. This sum is called the VIKSHEPA-KENDRA or the argument of latitude of the planet. As the PA'TA of the Moon lies in her concentric, and in this circle is her true place, the sum of these two is her VIKSHEPA-KENDRA, but the PA'TA of any other planet, Mars, &c. lies in its 2nd excentric and its MANDA-SPASHTA place (which is equivalent to its heliocentric place) is in that circle, therefore its VIKSHEPA-KENDRA is found by adding the place of its PA'TA to its MANDA-SPASHTA place. The SPASHTA-PA'TA of the planet is that which being added to the true place of the planet, equals its VIKSHEPA-KENDRA for this reason, it is found by reversely applying the 2nd equation to its mean PA'TA. As

∴ SPASHTA PA'TA + true place of the planet,
= VIKSHEPA-KENDRA,
= place of the MANDA SPASHTA planet + mean PA'TA,
= *p*, of the *m. s. p.* ± 2nd equation + *m.* P ∓ 2nd equation,
= true place of the planet + mean PA'TA ± 2nd equation,
∴ SPASHTA PA'TA = mean PA'TA ∓ 2nd equation.

The place of this SPASHTA PA'TA is to be reversely marked in the ecliptic from the stellar aries.—B. D]

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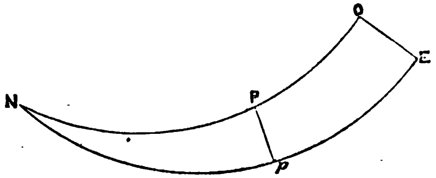
second hypothenuse becomes SPASHTA, rectified. The KSHEPA-VRITTA, or circles representing the orbits of the six planets, should be made separately. The Moon and the rest revolve in their own orbits.*

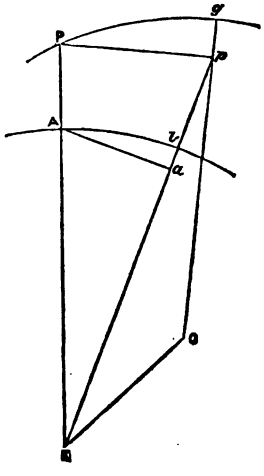
* [As the PA'TA of the Moon and her true place lie in her concentric, the sum of these two, which is called her VIKSHEPA-KENDRA or the argument of latitude, must be measured in the same circle, and her latitude, therefore found through her VIKSHEPA-KENDRA, will be as seen from the centre of her concentric i. e. from the centre of the Earth. But the PA'TA of any other planet and its MANDA-SPASHTA place (which is its heliocentric place) lie in its 2nd excentric, therefore its latitude, determined by means of its VIKSHEPA-KENDRA, which is equal to the sum of its MANDA-SPASHTA place and PA'TA and measured in the same circle, will be such as seen from the centre of its 2nd excentric and is called its mean latitude (which is equivalent to the heliocentric latitude of the planet).



As in Fig. 1, let N E be the quarter of the ecliptic, N O that of the 2nd excentric, N the node and P the planet. Suppose O E and P p (parts of great circles) to be drawn from O and P perpendicularly to the plane of the ecliptic: then O E will be the greatest latitude and P p the latitude of the planet at P, by which a spectator at the centre of the 2nd excentric and not at the centre of the Earth, will see the planet distant from the ecliptic. This latitude, therefore, is called a mean latitude which can be found as follows,

$$\sin N O : \sin O E :: \sin N P : \sin P p,$$
$$\text{or } R . \sin P p = \sin O E . \sin N p,$$

consequently, in order to determine P p, it is necessary to know previously O E, the greatest latitude and N P, the distance of the place of the planet from the node, which distance is evidently equal to the VIKSHEPA-KENDRA that is, to the sum of the MANDA-SPASHTA place of the planet and the mean place of the node. Now the latitude of the planet as seen from the centre of the Earth is called its true latitude. This true latitude can be found in the following manner,



Let E be the centre of the earth, O that of the 2nd excentric, P the MANDA SPASHTA place of the planet in it: then E P will be the 2nd hypothenuse which is supposed to cut the concentric at A: then A will be the true place of the planet in the concentric. Again let P q be a circle with the centre O, whose plane is perpendicular to the ecliptic plane and A b another circle with the centre E whose place is also perpendicular to the same plane, then P q will be the mean latitude of the planet and A b will be the true. Let P p and A a lines be perpendicularly drawn to the plane of the ecliptic, these lines will also be at right angles to the line E p: then P p will be the sine of the mean latitude P q and A a that of the true latitude A b. Now by the similar triangles E P p and E A a,

$$E P : P p :: E A : A a;$$
$$\therefore A a = \frac{E A . P p}{E P};$$

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16. The declination is an arc of a great meridian circle: cutting the equinoctial at right angles, and continued till it touch the ecliptic.

Declination and latitude.

$$\text{or the sine of the true latitude} = \frac{\text{R} \times \text{sine of the mean latitude}}{h}$$

$$\text{but, the sine of the mean latitude} = \frac{\sin \text{O E} \,.\, \sin \text{N P}}{\text{R}}$$

∴ by substitution

$$\text{the sine of the true latitude} = \frac{\text{R}}{h} \times \frac{\sin \text{O E} \,.\, \sin \text{N P}}{\text{R}}$$

$$= \frac{\sin \text{O E} \,.\, \sin \text{N P}}{h}$$

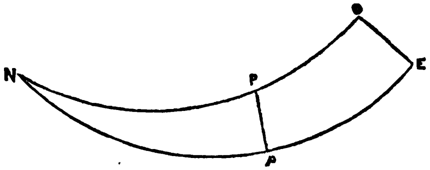
As the latitude of the planet is of a smaller amount, the arc of a latitude it, therefore taken in the SIDDHANTAS instead of the sine of the latitude.

$$\text{Hence, the true latitude} = \frac{\text{O E} \,.\, \sin \text{N P}}{h},$$

that is, the sine of the argument of latitude multiplied by the greatest latitude and divided by the 2nd hypothenuse is equal to the true latitude of the planet.

Now in the BHAGOLA, a circle should be so fixed to the ecliptic, that the former may intersect the latter at the SPASHTA-PÁTA and the point six signs from it, and whose extreme north and south distance from the ecliptic may be such that the distance between the circle and the ecliptic at the place of the true planet may be equal to the true latitude of the planet. This circle is called the VIMANḌALA or VIKSHEPA-VṚITTA and its extreme north and south distance from the ecliptic is called the true or rectified extreme latitude of the planet which can be found as follows.

Let N be the SPASHTA-PATA, N P the VIKSHEPA-KEN-DRA, P p the true latitude, E O the true extreme latitude: then sin N o : sin E O : : sin N P : sin P p



$$\therefore \sin \text{E O} = \frac{\sin \text{N O} \,.\, \sin \text{P}p}{\sin \text{N P}};$$

$$\text{or E O} = \frac{\text{R} \,.\, \text{P}p}{\sin \text{N P}};$$

$$\text{but if L be taken for the mean extreme latitude the P}\,p = \frac{\text{L} \,.\, \sin \text{N P}}{h}$$

$$\therefore \text{E O} = \frac{\text{R}}{\sin \text{N P}} \times \frac{\text{L} \,.\, \sin \text{N P}}{h} = \frac{\text{R} \,.\, \text{L}}{h},$$

This is the mean extreme latitude stated in the GANITADHYÁYA multiplied by the radius and divided by the 2nd hypothenuse equals the true or reccified extreme latitude.— B. D.]

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celestial latitude is in like manner an arc of a great circle (which passes through the ecliptic poles) intercepted between the ecliptic and the KSHEPA-VṚITTA.

The corrected declination [of any of the small planets and Moon] is the distance of the planet from the equinoctial in a circle of declination.

Precession of the equinox.

17. The point of intersection of the equinoctial and ecliptic circles is the KRÁNTI-PÁTA or intersecting point for declination. The retrograde* revolutions of that point in a KALPA amount to 30,000 according to the author of the SÚRYA-SIDDHÁNTA.

18. The motion of the solstitial points spoken of by MUNJÁLA and others is the same with this motion of the equinox: according to these authors its revolutions are 199,669 in a KALPA.

19. The place of the KRÁNTI-PÁTA, or the amount of the precession of the equinox determined through the revolutions of the KRÁNTI-PÁTA must be added to the place of a planet; and the declination then ascertained. The ascensional difference and periods of rising of the signs depend on the declination: hence the precession must be added to ascertain the ascensional difference and horoscope.

20. Thus the points of intersection of the ecliptic and the orbits of the Moon and other planets are the KSHEPA-PÁTAS, or intersecting points for the KSHEPA celestial latitude. The revolutions of the KSHEPA-PÁTAS are also contrary to the order of the signs, hence to find their latitudes, the places of the KSHEPA-PÁTAS must be added to the places of the planets (before found).

21. As the MANDA-SPASHTA planet (or the mean planet corrected by the 1st equation) and its ascending node revolve in the S'ÍGHRA-PRATIVṚITTA or 2nd excentric, hence the amount of the latitude is to be ascertained from (the place of) the MANDA-SPASHTA planet added to the node found by calculation.

* The motion of the KRÁNTI-PATA is in a contrary direction to that of the order of the signs.—L. W.

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22. Or the amount of the latitude may be found from the SPASHTA planet added to the node which the S'ÍGHRA-PHALA 2nd equation is added to or subtracted from accordingly as it was subtractive or additive.*

As the Moon's node revolves in the concentric circle, the amount of the latitude, therefore, is to be found from the true place of the Moon added to the mean node.

23. The exact revolutions of the nodes of Mercury and Venus will be found by adding the revolutions of their S'ÍGHRA-KENDRAS to the revolutions of their nodes which have been stated [in the GAṆITÁDHYÁYA]: if it be asked why these smaller amounts have been stated, I answer, it is for greater facility of calculation. Hence their nodes which are found from their stated revolutions are to be added to the places of their S'ÍGHRA-KENDRAS [to get the exact places of the nodes].†

24. To find the KENDRA [of any of the planets] the place of the planet is subtracted from the S'ÍGHROCHCHA: then take

* [See the nodes on V. 11, and V. 13, 14, 15. —B. D.]

† [In all the original astronomical works, the sum of the PA'TA and S'ÍGHROCHCHA of Mercury and Venus, is assumed for their VIKSHEPA-KENDRA, and through this, their latitude is determined. But the latitude thus found would be at the place of their S'ÍGHROCHCHA and not at their own place, because their places are different from those of their S'ÍGHROCHCHAS. To remove this difficulty, BHA'SKRA'CHA'RYA writes. "The exact revolutions &c." But the difficulty arises in the supposition that, the earth is stationary in the centre of the universe and all the planets revolve round her, because we are then bound to grant that the mean places of Mercury and Venus are equal to that of the Sun, and hence their places will be different from those of their S'ÍGHROCHCHAS. But no inconvenience occurs in the supposition that, the Sun is in the centre of the universe and all the planets together with the earth revolve round him. For, in this case the places of the S'ÍGHROCHCHAS of Mercury and Venus are their own heliocentric places, and consequently the sum of the places of their S'ÍGHROCHCHAS and PA'TAS will be equal to the sum of their own places and those of their PA'TAS, that is to their VIKSHEPAKENDRA. For this reason, their latitude found through this, will be at their own places. Now, it is a curious fact that, the revolutions of the pátas of Mercury and Venus, stated in the original works, are such as ought to be mentioned when it is supposed that the Sun is in the middle of the universe and the planets revolve round him, and not when the Earth is supposed to be stationary in the centre of the universe. From this fact, we can infer that the original Authors of the Astronomical works knew that all the planets together with the Earth revolve round the Sun, and consequently they stated the smaller amounts of the revolutions of the PA'TAS of the Mercury and Venus. When this is the case, why is it supposed that all the planets revolve round the Earth, because the Spherics can more easily be understood by this supposition than by the other.—B. D.]

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the KENDRA with the PÁTA added [to get the exact amount of the PÁTA or node] and let the place of the planet be added thereto, [we thus get the VIKSHEPA-KENDRA or the argument of the latitude of Mercury or Venus]. Therefore from the S'ÍGHROCHCHAS of these two planets with the PÁTAS added, their latitudes are directed by the ancient astronomers to be found.*

25 and 26. The PÁTAS or nodes of these two planets added to the S'ÍGHROCHCHRAS from which the true places of the planets have been subtracted, become SPASHṬA or rectified. It is the S'PASHTA-PÁTA which is found in the BHAGOLA (above described).

In the sphere of a planet, take the ecliptic above described as the concentric circle, to this circle the second excentric circle should be attached, as was explained before, and a circle representing the orbit of a planet (and which consequently would represent the real second excentric) should be also attached to the latter circle with the amount of latitude detailed for it. In this latter circle mark off the mean places of the nodes of the (superior) planets, and also mark in it the mean place of the nodes of Mercury and Venus added to their respective S'ÍGHRA-KENDRAS.†

Diurnal circles called AHOR'ATRA-VṚITTAS.

27. Next the AHOṚATRA-VRITTAS or diurnal circles, must be made on both sides of the equinoctial [and parallel to it] at every or any degree of declination that may be required:—and they must all be marked with 60 GHATIS: The radius of the diurnal circle [on which the Sun may move on any day] is called DYUJYÁ.

* [Let, h = S'ÍGHROCHCHA or the place of 2d higher apsis.
k = the S'ÍGHRA-KENDRA.
p = the place of the planet.
n = PA'TA or the place of the ascending node.
and $N.$ = the exact PA'TA.
then $k = h - p$; and $h = k + n = h. - p + n$;
∵ VIKSHEPA KENDRA or argument of latitude of Mercury or Venus = $N. + p = h. - p + n + p = h + n$.—B. D.]

† [See the note on verses 13, 14 and 15:—B. D.]

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28. From the vernal equinox mark the 12 signs in direct order, and then let diurnal circles be attached at the extremity of each sign.

29. On either side of the equinoctial, three diurnal circles should be attached in the order of the signs: these again will answer for the three following signs.

The BHAGOLA has thus been described. This is to be known also as the KHECHARA-GOLA, the sphere of a planet.

30. Or in the plane of the ecliptic bind the orbits of Saturn and of the other planets with cross diameters to support them, but these must be bound below (within) the ecliptic in successive circles one within the other, like the circles woven one within the other by the spider.

31. Having thus secured the BHAGOLA on the axis or YASHṬI, after placing it within the hollow cylinders on which the KHAGOLA is to be fastened, make the BHAGOLA revolve:—it will do so freely without reference to the KHAGOLA as its motion is on the solid axis. The KHAGOLA and DṚIGGOLA remain stationary whilst the BHAGOLA revolves.

End of Chapter VI. on the construction of an armillary sphere.

CHAPTER VII.

Called TRIPRAS'NA-VÁSANÁ *on the Principles of the Rules for resolving the questions on time, space, and directions.*

The ascensional difference and its place.

1. The time called CHARA-KHUNDA or ascensional difference is found by that arc of a diurnal circle intercepted between the horizon aud the six o'clock line. The sine of that arc is called the KUJYÁ in the diurnal circle: but, when reduced to relative

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value in a great circle, it is called CHARAJYÁ or sine of ascensional difference.*

2. The horizon, as seen at the equator, or in a right sphere, is denominated in other places [to the north, or south of the equator] the UNMANḌALA six o'clock line: but as the Sun appears at any place to rise on its own horizon, the difference between the times of the Sun's rising [at a given place and the equatorial region under the same meridian] is the ascensional difference.

Determination of the question when the CHARA correction is additive and when subtractive.

3. When the sun is in the northern hemisphere, it rises at any place (north of the equator) before it does to that on the equator: but it sets after it sets to that on the equator. Therefore the correction depending on the ascensional difference is to be subtracted at sunrise of a given place from the place of the planet [at sunrise at the equator] and to be added at sunset to the place of the planet [as found for the sunset at the equator].

4. When the Sun is in the southern hemisphere the reverse of this takes place, as the part of the UNMANDALA in that hemisphere lies below the horizon. The halves of the sphere north and south of the equinoctial are called the northern and southern hemispheres.

Cause of increase and decrease in length of days and nights.

5. [And it is in consequence of this ascensional difference that] the days are longer and the nights shorter (than they are on the

* [The times found by the arcs intercepted between the horizon and the six o'clock line, of the three diurnal circles attached at the end of the first 3 signs i. e. Aries, Taurus and Gemini are called the CHARA-KA'LAS or the ascensional differences of these signs, and the differences of these CHARA-KA'LAS are called the CHARA-KHANḌAS of those three signs.

As, where the PALABHA is 5 digits or the latitude is nearly 22½° north, the ascensional differences of the 3 first signs are 297, 541 and 642 ASUS, and the differences of those i. e. 297, 244 and 101 are the CHARA-KHANḌAS of those signs.

These are again the CHARA-KHANḌAS of the following three signs inversely i. e. 101, 244 and 297 ASUS.

Thus the CHARA-KHANḌAS of the first six signs answer for the following six signs.—B. D.]

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equator) when the Sun is in the northern hemisphere: and that the days are shorter and the nights longer when the Sun is in the southern hemisphere. For, the length of the night is represented by that arc of the diurnal circle below the horizon, and the length of the day by that arc above the horizon.

6. But at the equator the days and nights are always of the same length, as there is no UNMANḌALA there except the horizon [on the distance between which, the variation in the length of days and nights depends].

A circumstance of peculiar curiosity, however, occurs in those places having a latitude greater than 66° N. viz. than the complement of the Sun's greatest declination.

Determination of place and time of perpetual day and night.

7. Whenever the northern declination of the Sun exceeds the complement of the latitude, then there will be perpetual day for such time as that excess continued; and when the southern declination of the Sun shall exceed the complement of the latitude, then there will be perpetual night during the continuance of that excess. On MERU, therefore, day and night are each of half a year's length.

Place of MERU.

8. To the Celestial Beings [on MERU at the north pole] the equinoctial is horizon: so also is to the DAITYAS [at the south pole]. For, the northern and southern poles are situated respectively in their zeniths.

9. The Celestial Beings on MERU behold the Sun whilst he is in the northern hemisphere, always revolving above the horizon from left to right: but DAITYAS the inhabitants of the southern polar regions behold him whilst he is in the southern hemisphere revolving above their horizon from the right to the left.

Definition of the artificial day and night and the day and night of the PITṚIS.

10. Thus it is day whilst the Sun is visible, and night whilst he is invisible. As the determination of

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night and day is made in regard to men residing on the surface of the Earth, so also is that of the PITṚIS or deceased ancestors who dwell on the upper part of the Moon.

The meaning of the fact stated by the astrological professors or SA'NHITIKAS.

11. As for the doctrine of astrologers, that it was day with the Gods at MERU whilst the Sun was in the UTTARÁYAṆA (or moving from the winter to the summer solstice) and night whilst the Sun was in the DAKSHIṆÁYANA (or moving from the summer to the winter solstice), it can only be said in defence of such an assertion, that it is day when the Sun is turned towards the day, and it is night when turned towards the night. Their doctrine has reference merely to judicial astrology and the fruits it foretells.

12. By the degrees by which the Sun proceeds in his northern course to the end of Gemini, he moves back from that sign: entering also the same diurnal circles in his descent as he did in his ascent. Is it not therefore that the Sun is visible in his descent to the Gods in the place where he was first seen by them in his ascent?

Length of the day of the PITṚIS.

13. The PITRIS reside on the upper part of the Moon and fancy the fountain of nectar to be beneath themselves. They behold the Sun on the day of our AMÁVÁSYÁ or new Moon in their zenith. That therefore is the time of their midday.

14. They (i. e. the PITṚIS) cannot see the Sun when he is opposite the lower part of the Moon: it is therefore, midnight with the PITRIS on the day of the PÚRṆIMÁ or full Moon. The Sun rises to them in the middle of the KRISHNA PAKSHA or dark half of the Moon, and sets in the middle of the S'UKLA PAKSHA or light half of the Moon. This is clearly established from the context.

The explanation of a day of BRAHMA'.

15. As BRAHMÁ being at an immense distance from the Earth, always sees the Sun till the time of the PRALAYA or general deluge, and sleeps for the same time, therefore

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the day and night of BRAHMÁ are together of 2000 MAHÁYUGAS in length.

The time taken by each sign in rising above the horizon.

16. As the portion of the ecliptic which is more oblique than the other, rises and sets in a shorter time and that which is more upright takes a longer time in rising and setting, hence the times of rising of the several signs are various [even at the equatorial regions].

17. The (six) signs from Capricorn to Gemini or ascending signs which are inclined towards the south with their respective declinations whilst they rise even at the equator are still more inclined towards the south in the northern latitudes (on account of the obliquity of the starry sphere towards the south); hence they arise in still shorter times than they do at the equator.

18. At the equator, the [six] signs from Cancer or descending signs incline whilst they rise to the northerly direction, but they will have upright direction in consequence of the northern latitude, hence they rise in longer times [than they do at the equator.] The difference between the period of the rising of a sign in a given latitude, and at the equator under the same meridian, is equivalent to the CHARAKHAṆḌA of that sign.

19. Each quarter of the ecliptic rises in 15 GHAṬIS or 6 hours to those on the equator: and the 6 signs of the northern as well the 6 of the southern hemisphere appear to rise each in 12 hours or 30 GHAṬIS in every or any latitude.

20. The three signs from the commencement of Aries to the end of Gemini, i. e. the first quarter of the ecliptic, pass the UNMAṆḌALA in 15 GHAṬIS; but the horizon [of a place in north latitude] is below the UNMAṆḌALA, they therefore previously pass it in time less than 15 GHAṬIS by the CHARAKHAṆḌAS.

21. The three signs from the end of Virgo to the end of Sagittarius, i. e. the 3rd quarter of the ecliptic, pass the UNMAṆḌALA in 15 GHAṬIS; but they pass the horizon of a place

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afterwards which is above the UNMAṆḌALA [in north latitude] in 15 GHAṬIS added to the CHARAKHAṆḌAS.

22. The three signs from the end of Gemini to the end of Virgo, i. e. the 2nd quarter of the ecliptic or those from the end of Sagittarius to the end of Pisces i. e. the 4th quarter of the ecliptic, pass the horizon in the time equal to the remainder of 30 GHAṬIS diminished by the time which the first or third quarter takes to pass the horizon respectively. For this reason, the times which the signs contained in the 1st and 4th quarters of the ecliptic, or ascending signs, and those contained in the 2nd and 3rd quarters, or descending signs take to pass the horizon at a given place are found by subtracting the CHARAKHAṆḌAS of the signs from and adding them to the times which those signs take in rising on the equator respectively.*

23. Having placed the 1st Aries in the horizon and set the sphere in motion, the tutor should show the above facts to the

* The times taken by the several signs of the ecliptic in rising at the equator and in northern latitudes will be seen from the following memo. according to the SIDDHANTA.

	Times of rising at equator in sidereal time.	Ascensional differences in 22° 30′ north latitude sidereal time.	Times of rising in 22° 30′ north latitude sidereal time.	
	ASUS.	ASUS.	ASUS.	
Aries,	1670	— 297	1373	These 3 and the last 3 signs take less time to rise in north latitude than at the equator.
Taurus,	1793	— 244	1549	
Gemini,	1937	— 101	1836	
Cancer,	1937	+ 101	2038	These 6 signs take a longer time to rise in north latitude than at the equator.
Leo,	1793	+ 244	2037	
Virgo,	1670	+ 297	1967	
Libra,	1670	+ 297	1967	
Scorpio,	1793	+ 244	2037	
Sagittarius,	1937	+ 101	2038	
Capricorn,	1937	— 101	1836	
Aquarius,	1793	— 244	1549	
Pisces,	1670	— 297	1373	

L. W.

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pupils, that they may understand as well what has been explained as any other facts which have not been now mentioned.

24. In whatever time any sign rises above the horizon [in any latitude] the sign which is the 7th from it, will take exactly the same time in setting: as one half of the ecliptic is always above the horizon [in every latitude].

25. When the complement of latitude is less than 24° (i. e. than the extreme amount of the Sun's declination taken to be 24° by Hindu astronomers) then neither the rising periods of the signs, nor the ascensional differences and other particulars will correspond with what has been here explained. The facts of those countries (having latitudes greater than 66°) which are different from what has been explained on account of their totally different circumstances, are not here mentioned, as those countries are not inhabited by men.

Etymology of the word LAGNA.

26. That point of the ecliptic which is (at any time) on the eastern horizon is called the LAGNA or horoscope. This is expressed in signs, degrees, &c. reckoned from the first point of stellar Aries. That point which is on the western horizon is called the ASTA-LAGNA or setting horoscope. The point of the ecliptic on the meridian is called the MADHYA-LAGNA or middle horoscope (culminating point of the ecliptic).*

* [When the place of the horoscope is to be determined at a given time it is necessary at first to ascertain the height and longitude of the nonagesimal point from the right ascension of mid-heaven, and then by adding 3 signs to the longitude of the nonagesimal point, the place of the horoscope is found: but as this way for finding the place of the horoscope is very tedious, it has been determined otherwise in the SIDDHA'NTAS.

As, from the periods of risings of the 12 signs of the ecliptic which are determined in the Siddhantas, it is very easy to find the time of rising of any portion of the ecliptic and vice versa, we can find a portion of the ecliptic corresponding to the given time from sun-rise through the longitude of the Sun then determined and the given time. The portion of the ecliptic which can be thus found is evidently that portion of the ecliptic intercepted between the place of the Sun and the horizon. Therefore by adding this portion to the place of the Sun, the place of the horoscope is found. Upon this principle, the following common rule which is given in the SIDDHANTAS for finding the place of the horoscope is grounded.

Find first the true place of the Sun, and add to it the amount of the procession of the equinox for the longitude of the Sun. Then, from the longitude of the Sun, the sign of the ecliptic in which the Sun lies and the degrees of that sign

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27. If when you want to find the LAGNA, the given GHAṬIS are SÁVANA-GHAṬIS, then they will become sidereal by finding the Sun's instantaneous place i. e. the place of the Sun for the hour given. The times

The reason for finding the exact place of the Sun at the time of question in order to find LAGNA.

which he has passed, and those which he has to pass, are known. Thus the degrees which the Sun has passed, and those which he has to pass, are called the BHUKTÁNS'AS and BHOGYÁNS'AS respectively. Now the time which the Sun requires to pass the BHOGYÁNS'AS is called the BHOGYA time, and is found by the following proportion.

If 30°
: the period of rising of the sign in which the Sun is
: : BHOGYÁNS'AS
: BHOGYA time.

In the same manner, the BHUKTA time can also be found through the BHUKTÁNSAS.

Now from the time at the end of which the horoscope is to be found, and which is called the ISHTA or given time, subtract the BHOGYA time just found, and from the remainder subtract the periods of risings of the next successive signs to that in which the Sun is as long as you can. Then at last you will find the sign, the rising period of which being greater than the remainder you will not be able to subtract, and which is consequently called the AS'UDDHA sign, or the sign incapable of being subtracted, and its rising period, AS'UDDHA rising. From this it is evident that the AS'UDDHA sign is of course on the horizon at the given time. The degrees of the AS'UDDHA sign which are above the horizon and therefore called the BHUKTA or passed degrees, are found as follows.

If the rising period of the AS'UDDHA sign
: 30°
: : the remainder of the given time
: the passed degrees of the AS'UDDHA sign.

Add to these passed degrees thus found, the preceding signs reckoned from the 1st point of Aries, and from the Sum, subtract the amount of the procession of the equinox. The remainder thus found will be the place of the horoscope from the stellar Aries.

If the time at the end of which the horoscope is to be found, be given before sun-rise, then find the BHUKTA, or passed time of the sign in which the Sun is, in the way above shown, and subtract it and the rising periods of the preceding signs from the given time. After this find the degrees of the AS'UDDHA sign corresponding to the remainder of the given time which will evidently be the BHOGYA degrees of the horoscope by proportion as shown above, and subtract the sum of the BHOGYA degrees of the horoscope, the signs the rising periods of which are subtracted and the BHUKTA degrees of the sign in which the Sun is from the Sun's place and the remainder thus found will be the place of the horoscope.

Thus we get two processes; one when the given time at the end of which the horoscope is to be found, is after sun-rise, and the other when that time is given before sun-rise, and which are consequently called KRAMA, or direct, and VYUTKRAMA or undirect processes respectively.

It is plain from this that if the place of the Sun and that of the horoscope be known, the given time from sun-rise at the end of which the horoscope is found can be known by making the sum of the BHOGYA time of the sign in which the Sun is and the BHUKTA time of the horoscope and by adding to this sum the rising periods of intermediate signs.—B. D.]

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of rising of the signs which are sidereal must be subtracted from these GHAṬIS (of the question) reduced to a like denomination. When the hours of the question are already sidereal, there is no necessity for finding the sun's real place for that time.*

* [If it be asked whether the time at the end of which the horoscope is to be found is terrestrial or sidereal time; if it be terrestrial, how it is that you subtract from that the rising periods which are of different denomination on account of their being sidereal, and why the sun's instantaneous place i. e. the place determined for the hour given is used to ascertain the BHOGYA time, the given time is reckoned from sun-rise and the BHOGYA degrees of the sign in which the sun is, rise gradually above the horizon after sun-rise. Hence the BHOGYA degrees of the sign of the Sun's longitude, determined at the time of sun-rise, should be taken to find the place of the Horoscope, otherwise the place of the Horoscope will be greater than the real one. As for example, take the time from sun-rise, at the end of which the Horoscope is to be found, equal to 60 sidereal GHAṬIS and 44 ASUS when the Sun is in the vernal equinox at a place where the PALABHA is 5 digits or the latitude is 22°½ nearly, and ascertain the place of the Horoscope through the instantaneous place of the sun. Then, the place of the Horoscope thus found will be greater than the place of the Sun found at the time of next sun-rise, but this ought to be equal to it, and you will not be able to make this equal to the place of the Sun determined at the time of next sun-rise, unless you determine this through the place of the sun ascertained at sun-rise, and not through the Sun's instantaneous place. Hence it appears wrong to ascertain the place of the Horoscope through the Sun's instantaneous place. But the answer to this is as follows.

The GHAṬIS contained in the arc of the diurnal circle intercepted between that point of it where the Sun is, at a given time and the Horizon are the SÁVANA or terrestrial GHATIS, but the GHATIS contained in the arc of the diurnal circle intercepted between that point of it where the Sun was at the time of sun-rise and the Horizon are the sidereal, GHATIS. Thus it is plain from this that if the Sun's place determined at the time of sun-rise be given, the time between their place and the Horizon reckoned in the diurnal circle will evidently be the sidereal time and consequently the place of the Horoscope determined through this will be right. But if the instantaneous place of the Sun be given, the time given must be the SÁVANA time, because let the instantaneous place of the Sun be assumed for the Sun's place determined at the time of sun-rise, then the time between this assumed instantaneous place of the Sun and the Horizon, which is SÁVANA, will evidently be the sidereal time. Hence the fact as stated in the verse 27th is right.

Therefore if the Sun's instantaneous place and the place of the Horoscope be given, the time found through these will be the SÁVANA time, but if the place of the Horoscope and that of the Sun determined at the time of sun-rise be given, the time ascertained through these will be the sidereal time. And if you wish to find the SÁVANA time through the place of the Horoscope and that of the Sun determined at the time of the sun-rise assumed the sidereal time just found as a rough SÁVANA time and determined through this the instantaneous place of the Sun by the following proportion.

If 60 GHATIS
: Sun's daily motion
: : these rough SÁVANA GHATIS
: the Sun's motion relating to this time; and add then this result to the place of the Sun found at the time of sun-rise. The sum thus found will be the instantaneous place of the Sun nearly. Find the time again through this

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28. In those countries having a north latitude of 69° 20′ the signs sagittarius and capricornus are never visible: and the signs gemini and cancer remain always above the horizon.

Determination of latitudes in which different signs are always above and below the horizon.

29. In those places having a northern latitude of 78° 15′, the four signs scorpio, sagittarius, capricornus, and aquarius are never seen, and the four signs taurus, gemini, cancer, and leo, always appear revolving above the horizon.

30. On that far-famed hill of gold MERU which has a latitude of 90° N. the six signs of the southern hemisphere never appear above the horizon and the six northern signs are always above the horizon.

31. LALLA has declared that when the ASUS of CHARA-ḴHANḌA [in any latitude] are equal to the time which any sign takes to rise on the equator, then that sign will always remain visible above the horizon : but this assertion is without reason. Were it so, then in places having a latitude of 66°, the whole twelve signs of the ecliptic would always be visible, and would all appear at once on all occasions, as the times of their rising on the equator are equal to the ASUS of their CHARA-ḴHANḌAS : but this is not the fact.

An error of LALLA exposed.

32. LALLA has also stated in his work on the sphere that where the north latitude is 66° 30′, sagittarius and capricornus are not visible, and also that in north latitude 75°, scorpio and aquarius are never there visible : but this also is an idle assertion. How, my learned friend, has he managed to make so gross and palpable an error of three degrees ?*

Another gross error of LALLA.

instantaneous place of the Sun, and through this time ascertain the instantaneous place of the Sun. Thus you will get at last the exact SÁVANA time from sun-rise to the hour given by the repetition of this process. As the Sun is taken here for an example, you can find the SÁVANA time of any planet or any planetary time from the planet's rising to the hour given by the repetition of the aforesaid process.—B. D.]

* [BHÁSKARÁCHARYA means here that LALLA mentioning the degrees of latitudes, has committed a grand mistake in omitting 3 degrees, because he has

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33. The altitude of the polar star and its zenith distance as found by observation, give respectively the latitude and the LAMBÁNSA or complement of the latitude. Or the zenith distance and altitude of the Sun at mid-day when on the equinoctial give the latitude and its complement.

34. The UNNATA the time found in that arc of the diurnal circle which is intercepted between the eastern or western horizon and the planet above it, is SÁVANA. This is used in finding the shadow of the planet. The sine of the UNNAṬA which is oblique, like the AKSHA-KARṆA, by reason of the latitude, is called CHHEDAKA and not S'ANKU because it is upright.*

35. In order to find the shadow of the Moon, the UDITA (the time elapsed from the rising of a planet) which has been found by some astronomers by means of repeated calculation is erroneous, for the UDITA, (found by repeated calculation) is not SÁVANA. The labour of the astronomer that does not thoroughly understand mathematics as well the doctrine of the

stated in his work that sagittarius and capricornus are always visible in a place bearing a latitude 66° 30′, and scorpio and aquarius at 75° N., whereas this is not the case, those signs are always visible in the places bearing the latitudes 69° 30′ and 78° 15′ respectively as shown in the verses 28 and 29.—B. D.]

* [When the Sun is above the Horizon, the shadow caused by a gnomon 12 digits, high, is called the Sun's shadow according to the S'IDDHANTA languages and having at first determined the sine of the Sun's altitude and that of it complement through his UDITA time, astronomers ascertained this by the following proportion.

As the sine of the Sun's altitude
: the sine of its complement
: : gnomon of 12 digits
: the shadow caused by the gnomon.

Thus they determine the shadow of all planets, Moon, &c., and that of the fixed stars. Though the light of the five small planets, Mars, &c., and the fixed stars is not so brilliant, like that of the Sun and Moon, as to make their shadow visible, yet it is necessary to determine the shadow of any heavenly body in order to know the direction in which the body may be. Because, if the length and direction of the shadow of the body be known, the direction in which it is can be ascertained by spreading a thread from the end of its shadow through that of the gnomon. For, if you will fix a pipe in the direction of the thread thus spread, you will see through that pipe the body whose shadow is used here.

The time given for determination of any planet's shadow must be the SÁVANA time, because it is necessary to determine the degrees of altitude of a planet to know its shadow, and the degrees can be determined through the time contained in that arc of the diurnal circle intercepted between the planet and horizon. But the time contained in this arc cannot be other than the SÁVANA time.—B. D.]

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sphere, in writing a book of instruction on the science is utterly futile and useless.*

Determination of S'ANKU and DṚIGJYÁ.

36. The degrees of altitude are found in the DṚINMANḌALA or vertical circle, being the degrees of elevation in it above the horizon; the degrees of zenith distance are (as their name imports) the degrees in the same circle by which the object is distant from the zenith or mid-heaven of the observer: the S'ANKU is the sine of the degrees of altitude: and the DṚIGJYÁ is the sine of the zenith distance.

Of SAMA-S'ANKU, KOṆA-S'ANKU and MADHYA-S'ANKU.

37. When the Sun in his ascent arrives at the prime vertical, the S'ANKU found at the moment is the SAMA-S'ANKU: the S'ANKUS found at the moments of his passing the KOṆA-VṚITTA and the meridian are respectively termed the KOṆA-S'ANKU and MADHYA-S'ANKU.

Reason of the correction of parallax to the sine of altitude.

38. One-half of the vertical circle in which a planet is observed should be visible, but only one-half less the portion opposite the radius of the Earth is visible to observers on the surface of the Earth. Therefore $\frac{1}{15}$ part of the daily motion of the planet observed is to be subtracted from the sine of altitude or from the S'ANKU to find the shadow: [inasmuch as that amount is concealed by, or opposite to, the Earth].

The sine of amplitude and the UDAYASTA-SUTRA.

39. The AGRÁ (the sine of amplitude) is the sine of the arc of the horizon intercepted between the prime vertical and the planet's diurnal circle in the east or west i. e. between

* [In order to determine the Moon's shadow at a given time at full moon, some astronomers find her UDITA time i. e. the time elapsed from her rising to the hour given by the repeated calculation, through her instantaneous place and the place of the horoscope determined at the given hour. But they greatly err in this, because the time thus found will not be the S'AVANA time and consequently they cannot use this in finding the Moon's shadow. Their way for finding the UDITA time by the repeated calculation would be right, then only if the given place of the Moon would be such as found at the time of her rising and not her instantaneous place. Because her UDITA time found through her instantaneous place becomes S'AVANA at once without having a recourse to the repeated calculation, as it is shown in the note on the verse 27 of this Chapter.—B D.]

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the east or west point of the horizon, and the point of the horizon at which the planet rises or sets. The line connecting the points of the extremities of the east and west AGRÁ is called the UDAYÁSTA-SUTRA, the line of rising and setting.

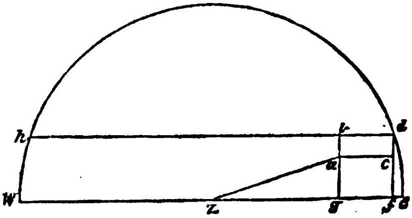
40. The S'ANKU-TALA or base of the S'ANKU stretches during the day to the south of the UDYÁSTA-SUTRA; because the diurnal circle have during the day a southern inclination (in northern latitude) above the horizon. But, below the horizon at night, the base lies to the north of the UDAYÁSTA-SUTRA as then the diurnal circles incline to the north. The S'ANKU-TALA's place has thus been rightly defined.

41. The S'ANKU-TALA lies to the south of the extreme point of AGRÁ when that AGRÁ is north and when the AGRÁ is south, the S'ANKU-TALA lies still to the south of it. The difference and sum of the sine of amplitude and S'ANKU-TALA has been denominated the BÁHU or BHUJA; it is the sine of the degrees lying between the prime vertical and the planet on the plane of the horizon.

42. [Taking this BÁHU as one side of a right-angled triangle.] The sine of the zenith distance being the hypothenuse then the third side or the KOṬI being the square root of the difference of their squares will be found: it is an east and west portion of the diameter of the prime vertical.*

I now propose to explain the triangles which are created by reason of the Sun's varying declination: and shall then proceed to explain briefly also the latitudinal triangles or those created by different latitudes. [The former are called KRÁNTI-KSHETRAS and the latter AKSHA-KSHETRAS.]

* Vide accompanying diagram.
a being place of the Sun: *d* its place of rising in the horizon: *d h* the UDAYÁ'STA-SÚTRA *d f* the AGRA': *a b* the S'ANKU-TALA: then *a g* is the BA'HU and the triangle *a z g* is the one here represented to.—L. W.



43. In the 1st triangle of declination.

1st. The sine of declination = BHUJA or base,

the radius of diurnal circle corresponding with the declination above given } = KOṬI or perpendicular,

and radius of large circle = hypothenuse.

2nd. Or in a right sphere.

The sine of 1, 2 or 3 signs = hypothenuse:

The declination of 1, 2 or 3 signs in six o'clock line } = BHUJAS.

44. Sines of arcs of diurnal circles corresponding with the declination above given } = KOṬIS.

These sines being converted into terms of a large circle: and their arcs taken, they will then express the times in ASUS which each sign of the ecliptic takes in rising at the equator i. e. the right ascensions of those signs or the LANKODAYAS, that is the 2nd will be found when the 1st is subtracted from two found conjointly, and the 3rd will be found when the sum of the 1st and 2nd is subtracted from three found conjointly.

45. In the right-angled triangle formed by the S'ANKU or gnomon when the Sun is on the equinoctial.*

Triangles arise from latitude.

1st. The S'ANKU of 12 digits = the KOṬI.

The PALABHÁ or the shadow of S'ANKU or gnomon } = the BHUJA

and the AKSHA-KARṆA { = the KARṆA or hypothenuse

or 2nd. The sine of latitude = BHUJA.

The sine of co-latitude = KOṬI

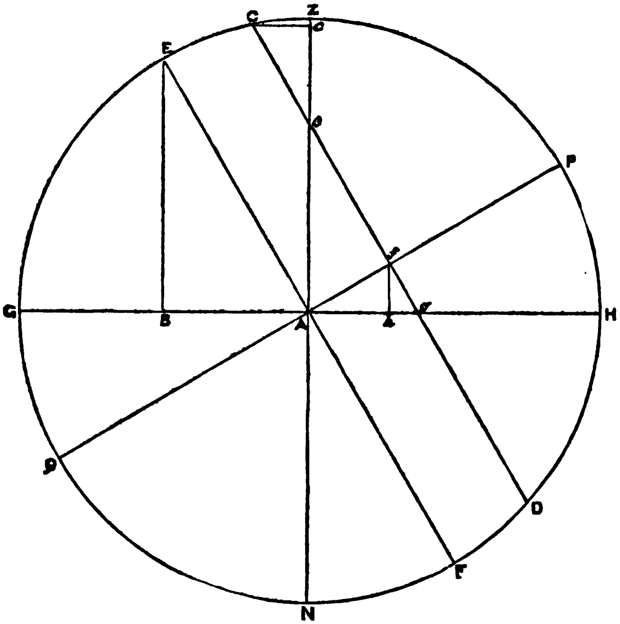
and radius = hypothenuse

This triangle is found in the plane of the meridian.

[* The right angle triangles stated in the five verses from 45 to 49, are clearly seen by fastening some diametrial threads within the armillary sphere. As

46. Or the sine of declination reckoned on the UNMANḌALA from the east and west line } = KOṬI.

KUJYÁ, the sine of ascensional difference in the diurnal circle of the given day } = BHUJA.



Let Z G N H be the meridian of the given place, G A H the diameter of the horizon, Z the Zenith, P and Q the north and south poles, E A F the diameter of the equinoctial, P A Q that of the six o'clock line, C *f* D that of one of the diurnal circles, and E B, *f h* the perpendiculars to G H. Then it is clear from this that

Z E or H P = the latitude,
A B = the sine of it,
E B = the co-sine of it,
A *f* = the declination of a planet revolving in the diurnal circle whose diameter is C D,
and ∴ A *g* = the AGRA or the sine of amplitude,
f g = the KUJYA',
A *e* = the SAMA-SA'NKU or the sine of the planet's altitude when it reaches the prime vertical.
e g = the TADDHṚITI,
e f = the TADDHṚITI—KUJYA',
f h = the UNMANḌALA S'ANKU or the sine of the planet's altitude when it reaches the six o'clock line,
A *h* = the AGRA'DI-KHANḌA or the 1st portion of the sine of amplitude,
and *h g* = the AGRA'GRA-KHANḌA or the 2nd portion of the sine of amplitude;

The sine of amplitude in the horizon = hypothenuse

This is a well known triangle.

47. Or the SAMA S'ANKU in the prime vertical being } = KOṬI

The sine of amplitude = BHUJA

The TADDHṚITI in the diurnal circle = hypothenuse

Or

Taking the sine of declination = BHUJA

and the SAMA-S'ANKU = hypothenuse

TADDHṚITI *minus* KUJYÁ = KOṬI.

48. The UNMANḌALA S'ANKU being = BHUJA

The sine of declination will then be = hypothenuse

And AGRADI KHANDA or 1st portion of the sine of amplitude will be } = KOṬI

Therefore, with the exception of the first and last the other six triangles stated in the verses are these in succession. A E B, A *g f*, A *e g*, A *e f*, A *f h* and *g f h* and the first triangle you will get by dividing the three sides of the triangle A E B by $\frac{\text{E B}}{12}$ and for the last see the note on the verse 49.

It is clear from the above described diagram that all of these triangles are similar to each other and consequently they can be known by means of proportion if any of them be known.

The SIDDHÁNTIS, having thus produced several triangles similar to these original by fastening the threads within the armillary sphere, find answers of the several questions of the spherical trigonometry. Some problems of the spherical trigonometry can be solved with greater facility by this SIDDHANTA way than the trigonometrical way. As

Problem. The zenith distances of a star when it has reached the prime vertical and the meridian at a day in any place are known, find the latitude in the place.

The way for finding the answer of this problem according to the SIDDHANTA is as follows.

Draw C c ⊥ A Z, (See the proceeding diagram) then C c e will be a latitudinal triangle.

Now, let a = C c, the sine of zenith distance,
b = A c, the co-sine of Z c,
c = A e, the SAMA-S'ANKU,
and x = the latitude.

Then C $e = \sqrt{a^2 + (b-c)^2}$,

and C e : C c : : A E : A B,

or $\sqrt{a^2 + (b-c)^2} : a :: \text{rad} : \sin x$;

$$\therefore \sin x = \frac{a \times \text{Rad}}{\sqrt{a^2 + (b-c)^2}}.$$—B. D.]

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Or

Making the UNMANḌALA SANKU	= KOṬI
the AGRÁGRA-KHANḌA or 2nd portion of the sine of amplitude is	= BHUJYA
the KUJYA then becomes	= hypothenuse
49.* The S'ANKU being	= KOṬI
and the S'ANKU-TALA	= BHUJA
Then the CHHEDAKA or HṚITI	= hypothenuse

Those who have a clear knowledge of the spherics having thus immediately formed thousands of triangles should explain the doctrine of the sphere to their pupils.

End of Chapter VII. on the principles of the rules for resolving the questions on time, space and directions.

CHAPTER VIII.

Called GRAHAṆA VÁSANÁ.

In explanation of the cause of eclipses of the Sun and Moon.

The cause of the directions of the beginning and end of the solar eclipse.

1. The Moon, moving like a cloud in a lower sphere, overtakes the Sun [by reason of its quicker motion and obscures its shining disk by its own dark body :] hence it arises that the western side of the Sun's disk is first obscured, and that the eastern side is the last part relieved from the Moon's dark body : and to some places the Sun is eclipsed and to others is not eclipsed (although he is above the horizon) on account of their different orbits.

* This triangle differs from the 1st of the 47th verse only in this respect that the base of the triangle in the 47th verse is equal to the sine of the *whole amplitude* while the base found when the Sun is not in the prime vertical, will always be more or less than the sine of amplitude and is therefore generally called SANKUTALA.—L. W.

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2. At the change of the Moon it often so happens that an observer placed at the centre of the Earth, would find the Sun when far from the zenith, obscured by the intervening body of the Moon, whilst another observer on the surface of the Earth will not at the same time find him to be so obscured, as the Moon will appear to him [on the higher elevation] to be depressed from the line of vision extending from his eye to the Sun. Hence arises the necessity for the correction of parallax in celestial longitude and parallax in latitude in solar eclipses in consequence of the difference of the distances of the Sun and Moon.

The cause of the parallax in longitude and that in latitude.

3. When the Sun and Moon are in opposition, the Earth's shadow envelopes the Moon in darkness. As the Moon is actually enveloped in darkness, its eclipse is equally seen by every one on the Earth's surface [above whose horizon it may be at the time] : and as the Earth's shadow and the Moon which enters it, are at the same distance from the Earth, there is therefore no call for the correction of the parallax in a lunar eclipse.

The reason of the correction of parallax not being necessary in lunar eclipses.

4. As the Moon moving eastward enters the dark shadow of the Earth : therefore its eastern side is first of all involved in obscurity, and its western is the last portion of its disc which emerges from darkness as it advances in its course.

The cause of the directions of the beginning and end of the lunar eclipse.

5. As the Sun is a body of vast size, and the Earth insignificantly small in comparison : the shadow made by the Sun from the Earth is therefore of a conical form terminating in a sharp point. It extends to a distance considerably beyond that of the Moon's orbit.

6. The length of the Earth's shadow, and its breadth at the part traversed by the Moon, may be easily found by proportion.

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In the lunar eclipse the Earth's shadow is northwards or southwards of the Moon when its latitude is south or north. Hence the latitude of the Moon is here to be supposed inverse (i. e. it is to be marked reversly in the projection to find the centre of the Earth's shadow from the Moon.)

The determination of the coverer in the eclipse of the Sun and Moon.

7. As the horns of the Moon, when it is half obscured form very obtuse angles: and the duration of a lunar eclipse is also very great, hence the coverer of the Moon is much larger than it.

8. The horns of the Sun on the contrary when half of its disc is obscured form very acute angles: and the duration of a solar eclipse is short: hence it may be safely inferred that the dimensions of the body causing the obscuration in a solar eclipse are smaller than and different from the body causing an eclipse of the Moon.*

9. Those learned astronomers, who, being too exclusively devoted to the doctrine of the sphere, believe and maintain that Ráhu cannot be the cause of the obscuration of the Sun and Moon, founding their assertions on the above mentioned contrarieties, and differences in the parts of the body first obscured, in the place, time, causes of obscuration &c. must be admitted to assert what is at variance with the Sanhitá, the Vedas and Puráṇas.

10. All discrepancy, however, between the assertions above referred to and the sacred scriptures may be reconciled by understanding that it is the dark Ráhu which entering the Earth's shadow obscures the Moon, and which again entering the Moon (in a solar eclipse) obscures the Sun by the power conferred upon it by the favour of Brahmá.

* [Had the Sun's coverer been the same with that of the Moon, his horns, when he is half eclipsed, would have formed, like those of the Moon obtuse angles. For the apparent diameters of the Sun and Moon are nearly equal to each other. Or the Moon when it is half eclipsed would have represented its horns, like those of the Sun, forming acute angles, if its coverer had been the same with that of the Sun. But as this is not the case, the coverer of the Moon is, of course, different and much larger than that of the Sun.—B. D.]

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What is the cause of parallax, and why it is calculated from the radius of the Earth.

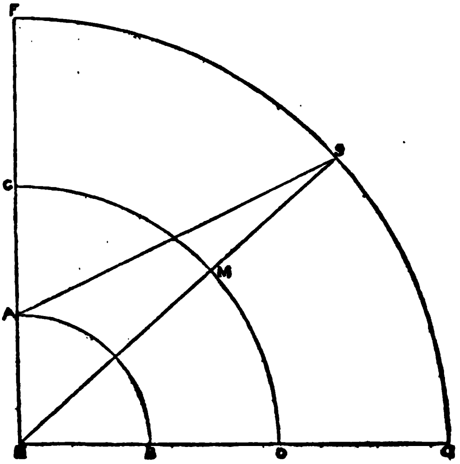
11. As the spectator is elevated above the centre of the earth by half its diameter, he therefore sees the Moon depressed from its place [as found by a calculation made for the centre of the Earth]. Hence the parallax in longitude is calculated from the radius of the Earth, as is also the parallax in latitude.

Construction of diagram to illustrate the cause of parallax.

12. Draw upon a smooth wall, the sphere of the earth reduced to any convenient scale, and the orbits of the Moon and Sun at proportionate distances: next draw a transverse diameter and also a perpendicular diameter to both orbits.*

13, 14 and 15. Those points of the orbits cut by this diameter are on the (rational) horizon. And the point above

Fig. 1.



* In Fig. 1, let E be the centre of the earth; A a spectator on her surface; C D, F G the vertical circles passing through the Moon M, and the Sun S; D, G the points of the horizon cut by the vertical circles C D, F G; and C, the zenith in the Moon's sphere, and F in that of the Sun. Now, let E M S be a line drawn from the centre of the Earth to the Sun in which the Moon lies always at the time of conjunction, and A S the vision line drawn from the spectator A to the Sun. The distance at which the Moon appears depressed from the vision line in the vertical circle is her parallax from the Sun.

When the Sun reaches the zenith F, it is evident that the Moon also will then be at C and the vision line, and the line drawn from the centre of the Earth will be coincident. Hence there is no parallax in the zenith.

Thus the parallax of the Moon from the Sun in the vertical circle is here shown by means of a diagram which becomes equal to the difference between the parallaxes of the Sun and Moon separately found in the vertical circle as stated by BHA'SKARA'CHA'RYA in the chapter on eclipses in the commentary VA'SANA'BHA'SHYA and the theories and methods are also given by him on the parallaxes of the Sun and Moon. This parallax in the vertical circle which arises from the zenith distance of the planet is called the common parallax or the parallax in altitude.

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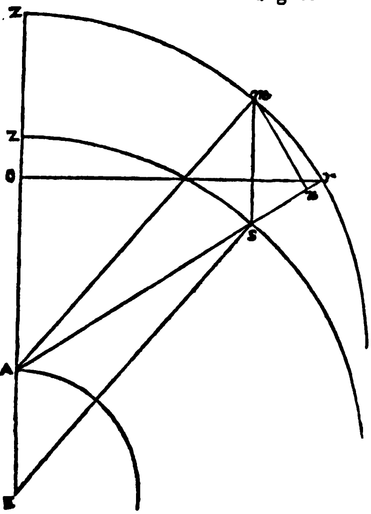
cut by the perpendicular diameter will represent the observer's zenith: Then placing the Sun and Moon with their respective zenith distances [as found by a proportional scale of sines and arcs,] let the learned astronomer show the manner in which

Fig. 2.



As in Fig. 2, let A be a spectator on the earth's surface; Z the zenith; and Z S the vertical circle passing through the planet S: Let a circle Z′ *m r* be described with centre A and radius E S which cuts the lines A Z and A S produced in the points Z′ and *r*: Let a line *s m* be drawn parallel to E Z, then the arc Z′ *m* will be equal to the arc Z S. Now the planet S seen from E has a zenith distance Z S and from A, a zenith distance Z′ *r* greater than Z S or Z′ *m* by the arc *m r*, hence the apparent place *r* of the planet is depressed by *m r* in the vertical circle. This arc *m r* is therefore the common parallax of the planet, which can be found as follows.

Draw *m n* perpendicular to A *r* and *r o* to A Z and let P = E S or A *r*;
h = E A or *m* S;
p = *m r* the parallax;
d = Z S or Z′ *m* the true zenith distance of the planet;
and ∴ $d + p$ = Z′ *r* the apparent zenith distance of the planet.

Then *m n* = sin *p* and *r o* = sin $(d + p)$.

Now by similar triangles A *r o*, S *m n*.

$$Ar : ro = Sm : mn,$$

$$\text{or } R : \sin(d+p) = h : \sin p;$$

$$\therefore \sin p = \frac{h \times \sin(d+p)}{R}.$$

Hence, it is evident from this that when the $\sin(d+p) = R$ or $d + p = 90°$, then the parallax will be greatest and if it be denoted by P,

$$\sin P = h \text{ and } \therefore \sin p = \frac{\sin P \times \sin(d+p)}{R}$$

Now, the parallax is generally so small that no sensible error is introduced by making $\sin p = p$ and $\sin P = P$;

$$\therefore p = \frac{P \times \sin(d+p)}{R};$$

Again, for the reason just mentioned sin *d* is assumed for $\sin(d+p)$ in the SIDDHÁNTAS,

$$\therefore p = \frac{P. \sin d}{R}$$

that is, the common parallax of a planet is found by multiplying the greatest parallax by the sine of the zenith distance and dividing the product by the radius.—B. D.]

the parallax arises. [For this purpose] let him draw one line passing the centre of the earth to the Sun's disc: and another which is called the DṚIKSÚTRA or line of vision, let him draw from the observer on the Earth's surface to the Sun's disc. The minutes contained in the arc, intercepted between these two lines give the Moon's parallax from the Sun.

16. (At the new Moon) the Sun and Moon will always appear by a line drawn from the centre of the earth to be in exactly the same place and to have the same longitude: but when the Moon is observed from the surface of the Earth in the DṚIKSÚTRA or line of vision, it appears to be depressed, and hence the name LAMBANA, or depression, for parallax.

17. (When the new Moon happens in the zenith) then the line drawn from the Earth's centre will coincide with that drawn from its surface, hence a planet has no parallax when in the zenith.

Now on a wall running due north and south draw a diagram as above prescribed; [i. e. draw the Earth, and also the orbits of the Sun and Moon at proportionate distances from the Earth, and also the diameter transverse and perpendicular, &c.]

18. The orbits now drawn, must be considered as DṚIKSHEPA-VṚITTAS or the azimuth circles for the nonagesimal. The sine of the zenith distance of the nonagesimal or of the latitude of the zenith is the DṚIKSHEPA of both the Sun and Moon.

19. Mark the nonagesimal points on the DṚIKSHEPA-VṚITTAS at the distance from the zenith equal to the latitude of the points. From these two points (supposing them as the Sun and Moon) find as before the minutes of parallax in altitude. These minutes are here NATI-KALÁS, i. e. the minutes of the parallax in latitude of the Moon from the Sun.

20. The difference north and south between the two orbits i. e. the measure of their mutual inclination, is the same in every part of the orbit as it is in the nonagesimal point, hence this difference called NATI is ascertained through the DṚIKSHEPA or the sine of the zenith distance of the nonagesimal.*

[* When the planet is depressed in the vertical circle, its north and south

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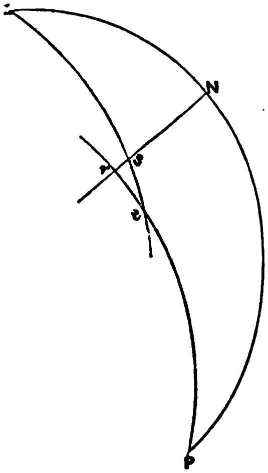
21. The amount by which the Moon is depressed below the Sun deflected from the zenith [at the conjunction] wherever it be, is the east and west difference between the Sun and Moon in a vertical circle.*

distance from its orbit caused by this depression is called NATI or the parallax in latitude.

Fig. 3.



As, in Fig. 3, let Z be the zenith; N the nonagesimal; Z N P its vertical circle; N *s r* the ecliptic; P its pole; Z *s t* the vertical circle passing through the true place S and the depressed or apparent place *t* of the Sun; P *t r* a secondary to the ecliptic passing through the apparent place *t* of the Sun; then *s r* is the SPASHṬA LAMBANA or the parallax in longitude and *t r* the NATI or the parallax in latitude which can be found in the following manner according to the SIDDHÁNTAS.

Let Z N be the zenith distance of the nonagesimal and Z S that of the Sun; then by the triangles Z N S, *t s r*

$$\sin ZS : \sin ZN = \sin st : \sin rt,$$

$$\therefore \sin rt = \frac{\sin st \times \sin ZN}{\sin ZS};$$

Now, *s t* is taken for sin *s t*, and *r t* for sin *r t*, on account of their being very small

$$\therefore rt = \frac{st \times \sin ZN}{\sin ZS};$$

but according to the SIDDHÁNTAS

$$st = \frac{P \,.\, \sin ZS}{R} \text{ (see the preceding note)..} \quad (1)$$

$$\therefore rt = \frac{P \,.\, \sin ZN}{R} \text{.........................} \quad (2)$$

that is, the NATI is found by multiplying the sine of the latitude of the nonagesimal by the greatest parallax and dividing the product by the radius.

It is clear from this that the north and south distance from the Sun depressed in the vertical circle to the ecliptic wherever he may be in it, becomes equal to the common parallax at the nonagesimal, and hence the NATI is to be determined from the zenith distance of the nonagesimal.

For this reason, by subtracting the NATI of the Sun from that of the Moon, which are separately found in the way above mentioned, the parallax in latitude of the Moon from the Sun is found: and this becomes equal to the difference between the mean parallaxes of the Sun and Moon at the nonagesimal. The same fact is shown by BHÁSKARÁCHÁRYA through the diagrams stated in the verses 12th &c.

At the time of the eclipse as the latitude of the Moon revolving in its orbits is very small, the Moon, therefore, is not far from the ecliptic; and hence the parallax in longitude and that in latitude of the Moon is here determined from her corresponding place in the ecliptic, on account of the difference being very small.—B. D.]

* [According to the technicality of the Siddhantas, the distance taken in any circle from any point in it, is called the east and west distance of the point, and

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22. For this reason, the difference is two-fold, being partly east and west, and partly north and south. And the ecliptic is here east and west, and the circle secondary to it is north and south. (It follows from this, that the east and west difference lies in the ecliptic, and the north and south difference in the secondary to it.)

23. The difference east and west has been denominated LAMBANA or parallax in longitude, whilst that running north and south is parallax in latitude.

24. The parallax in minutes as observed in a vertical circle, forms the hypothenuse of a right angle triangle, of which the NATI-KALÁ or the minutes of the parallax in latitude form one of the sides adjoining the right angle then the third side found by taking the square-root of the difference of the squares of the two preceding sides will be SPHUTA-LAMBANA-LIPTÁ or the minutes of the parallax in longitude.*

25. The amounts in minutes of parallax in a vertical circle may be found by multiplying the sine of the Sun's zenith distance of the minutes of the extreme or horizontal parallax and dividing the product by the radius. Thus the NATI will be found from the DṚIKSHEPA or the sine of the nonagesimal zenith distance.†

26. The extreme or horizontal parallax of the Moon from the Sun amounts to $\frac{1}{15}$ part of the difference of the Sun's and Moon's daily motion. For $\frac{1}{15}$ part of the YOJANAS, the distance of which any planet traverses per diem (according to the SIDDHÁNTAS) is equal to the Earth's radius.

27. The minutes of the parallax in longitude of the Moon from the Sun divided by the difference in degrees of the daily

the distance taken in the secondary to that circle from the same point, is called the north and south distance of that point.—B. D.]

* [See Fig. 3, in which by assuming the triangle $r\,s\,t$ as a plane right-angled triangle, $r\,t$ = base, $s\,t$ = hypothenuse and $s\,r$ = perpendicular, and therefore $s\,r = \sqrt{s\,t^2 - r\,t^2}$.—B. D.]

† [This is clear from the equations (1) and (2) shown in the preceding large note.—B. D.]

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motions of the Sun and Moon will be converted into GHAṬIS [i. e. the time between the true and apparent conjunction].*

If the Moon be to the east [of the nonagesimal], it is thrown forward from the Sun, if to the west it is thrown backward (by the parallax).

28. And if the Moon be advanced from the Sun, then it must be inferred that the conjunction has already taken place by reason of the Moon's quicker motion; if depressed behind the Sun, then it may be inferred that the conjunction is to come by the same reason.

Hence the parallax in time, if the Moon be to the east [of the nonagesimal] is to be subtracted from the end of the TITHI or the hour of ecliptic conjunction, and to be added when the Moon is to the west [of the nonagesimal].

29. The latitude of the Moon is north and south distance between the Sun and Moon, and the NATI also is north and south. Hence the S'ARA or latitude applied with the NATI or the parallax in latitude, becomes the apparent latitude (of the Moon from the Sun).

VALANA or variation (of the ecliptic).

[The deviation of the ecliptic from the eastern point (in reference to the observer's place) of a planet's disc, situated in the ecliptic is called the VALANA or variation (of the ecliptic). It is evident from this, that the variation is equivalent to the arc which is the measure of the angle formed by the ecliptic and the secondary to the circle of position at the planet's place in the ecliptic. It is equal to that arc also, which is the

* It is clear from the following proportion.
If difference in minutes of daily motions of Sun and Moon.
: 60 GHATIS — what will
: : given LAMBANA—KA'LAS or minutes of the parallax give ;

$$\text{or } \frac{60 \times \text{given minutes of the parallax}}{\text{diff. in minutes of Sun's and Moon's motions}} = \frac{\text{given minutes of the parallax}}{\text{diff. in degrees of Sun's and Moon's motions}} = \text{acceleration or delay of conjunction arising from parallax.}$$

—L. W.

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measure of the angle at the place of the planet in the ecliptic formed by the circle of position and the circle of latitude. It is very difficult to find it at once. For this reason, it is divided into two parts called the ÁKSHA-VALANA (latitudinal variation) and the ÁYANA-VALANA (solstitial variation). The ÁKSHA-VALANA is the arc which is the measure of the angle formed by the circle of position, and the circle of declination at the place of the planet in the ecliptic, and the ÁYANA-VALANA is the arc which is the measure of the angle formed by the circle of declination and the circle of latitude. This angle is equivalent to the angle of position. From the sum or difference of these two arcs, the arc which is the measure of the angle formed by the circle of position and the circle of latitude is ascertained, and hence it is sometimes called the S'PASHṬA-VALANA or rectified variation.

Now, according to the phraseology of the SIDDHÁNTAS, the point at a distance of 90° forward from any place in any circle is the east point of that place, and the point at an equal distance backwards from it is the west point. And, the right hand point, 90° distant from that place, in the secondary to the former circle, is the south point, and the left hand point, is the north point. According to this language, the deviation of the east point of the place of the planet in the ecliptic, from the east point in the secondary to the circle of position at the planet's place, is the VALANA. But the secondary to the circle of position will intersect the prime vertical at a distance of 90° forward from the place of the planet, and hence the deviation of the east point in the ecliptic from the east point in the prime vertical is the VALANA or variation, and this results equally in all directions. When the east point in the ecliptic is to the north of the east point in the prime vertical, the variation is north, if it be to the south, the variation is south.

The use of the VALANA is this that, in drawing the projections of the eclipses, after the disc of the body which is to be eclipsed is drawn, and the north and south and the east and

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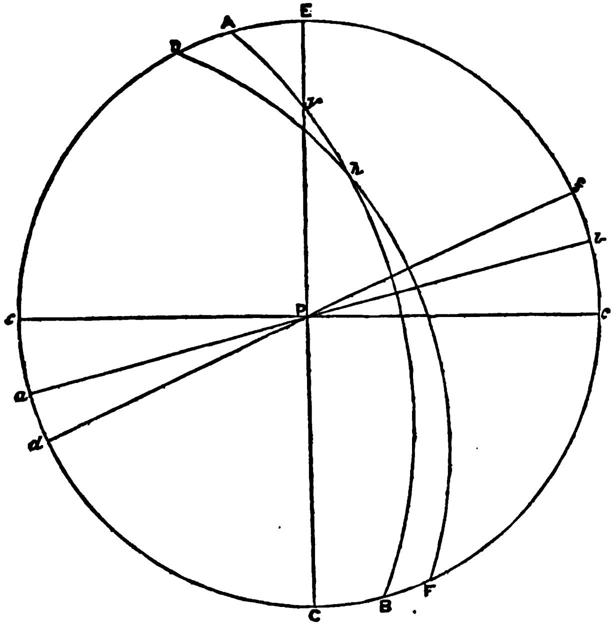
west lines are also marked in it, which lines will, of course, represent the circle of position and its secondary, the direction of the line representing the ecliptic in the disc of the body can easily be found through the VALANA. This direction being known, the exact directions of the beginning, middle and the end of the eclipse can be determined. But as the Moon revolves in its orbit, the direction of its orbit, therefore, is to be found. But the method for finding this is very difficult, and consequently instead of doing this, Astronomers determined the direction of the ecliptic, by means of the Moon's corresponding place in it and then ascertain the direction of the Moon's orbit.

The VALANA will exactly be understood by seeing the following diagram



Let E P C be the ecliptic, P the place of the planet in it, A *h* B the equinoctial, V the vernal equinox, D *h* F the prime vertical, *h* the point of intersection of the prime vertical and

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the equinoctial, hence h the east or west point of the horizon and D h equivalent to the NATA which is found in the V. 36. Again, let e P c, a P b and d P f be the circles of latitude, declination and position respectively passing through the place of the planet in the ecliptic.

Then,

the arc f b which is the measure of ∠ b P f = the ÁKSHA-VALANA :

the arc b c .... ∠ c P b = the ÁYANA-VALANA :

and the arc f c .... ∠ c P f = the SPASHṬA-VALANA.

Or according to the phraseology of the SIDDHÁNTAS

E the east point of P in the ecliptic;

A .... the equinoctial;

D .... the prime vertical;

hence,

the distance from D to A or arc D A or f b = the ÁKSHA-VALANA :

.... A to E or arc A E or b c = the ÁYANA-VALANA :

and .... D to E or arc D E or f c = the SPASHṬA-VALANA or rectified variation.

These arcs can be found as follows

Let, l = longitude of the planet,

e = obliquity of the ecliptic,

d = declination of the planet,

L = latitude of the place,

n = NATA,

x = ÁYANA-VALANA,

y = ÁKSHA-VALANA,

and Z = rectified VALANA.

Then, in the spherical triangle A V E,

sin E A V : sin A V E = sin E V : sin A E,

or cos d : sin e = cos l : sin x,

$$\therefore \sin x \text{ or sine of the ÁYANA-VALANA} = \frac{\sin e \,.\, \cos l \,.}{\cos d} \quad \text{(A)}$$

See V. 32, 33, 34.

This VALANA is called north or south as the point E be north or south to the point A.

And, in the triangle A h D.

$$\sin \text{D A } h : \sin \text{A } h \text{ D} = \sin \text{D } h : \sin \text{D A};$$

here, $\sin \text{D A } h = \sin \text{E A V} = \cos d$,

$\sin \text{A } h \text{ D} = \sin \text{L}$,

and $\sin \text{D } h = \sin n$,

$\therefore \quad \cos d : \sin \text{L} = \sin n : \sin y$,

$$\therefore \quad \sin y \text{ or sine of the ÁKSHA-VALANA} = \frac{\sin \text{L}.\ \sin n}{\cos d} \quad \text{(B)}$$

See V. 37.

The ÁKSHA-VALANA is called north or south as the point A be north or south to the point D.

And the rectified VALANA D E = D A + A E, when the point A lies between the points D and E, but if the point A be beyond them, the rectified VALANA will be equal to the difference between the ÁKSHA and ÁYANA-VALANA. This also is called north or south as the point E be north or south to the point D.

The ancient astronomers LALLA, S'RÍPATI &c. used the co-versed sin l instead of cos l and the radius for the cos d in (A) and the versed sin n in the place of sin n and radius for the cos d in (B) and hence, the VALANAS, found by them are wrong. BHÁSKARÁCHÁRYA therefore, in order to convince the people of the said mistake made by LALLA, S'RÍPATI, &c. in finding the VALANAS refuted them in several ways in the subsequent parts of this chapter.—B. D.]

ÁYANA-VALANA.

30. In either the 1st Libra or the 1st Aries in the equinoctial point of intersection of the equinoctial and ecliptic, the north and south lines of the two circles i. e. their secondaries are different

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and are at a distance* of the extreme declination (of the Sun i. e. 24°) from each other.

31. Hence, the ÁYANA-VALANA will then be equal to the sine of 24° :—The north and south lines of these two circles however are coincident at the solstitial points.

32, 33 and 34. And the north and south lines being there coincident, it follows as a matter of course that the east of those two circles will be the same. Hence at the solstitial points there is no (ÁYANA) VALANA.

When the planet is in any point of the ecliptic between the equinoctial and solstitial points, ÁYANA-VALANA is then found by proportion, or by multiplying the co-sine of the longitude of the planet by the sine of 24°, and dividing the product by the DYUJYÁ or the co-sine of the declination of the planet. This ÁYANA-VALANA is called north or south as the planet be in the ascending or descending signs respectively.

ÁKSHA-VALANA.

Thus in like manner at the point of intersection of the prime vertical and equinoctial, the six o'clock line is the north and south line of the equinoctial, whilst the horizon (of the given place) is the north and south line of the prime vertical. The distance of these north and south lines is equal to the latitude (of the place).

35. Hence at (the east or west point of) the horizon, the ÁKSHA-VALANA is equal to the sine of the latitude. At midday the north and south line of the equinoctial and prime vertical is the same. Hence at midday there is no ÁKSHA-VALANA.

36. For any intervening spot, the ÁKSHA-VALANA is to be found from the sine of the NATA† by proportion.

First, the degrees of NATA are (nearly) to be found by multiplying the time from noon by 90 and dividing the product by the half length of day.

* [By the distance of any two great circles is here meant an arc intercepted between them, of a great circle through the poles of which they pass.—B. D.]

† [Here the NATA is the arc of the prime vertical intercepted between the zenith and the secondary circle to it passing through the place of the planet.—B. D.]

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37. Then the sine of the NATA degrees multiplied by the sine of latitude, and divided by the co-sine of the declination of the planet will be the ÁKSHA-VALANA. If the NATA be to the east, the ÁKSHA-VALANA is called north. If west, then it is called south (in the north terrestrial latitude).

SPASHṬA-VALANA.

The sum and difference of the ÁYANA and ÁKSHA-VALANAS must be taken for the SPASHṬA-VALANA, viz. their sum when the ÁYANA and ÁKSHA-VALANAS are both of the same denomination, and their difference when of different denominations i. e. one north and the other south.

38. When the planet is at either the points of the intersection of the ecliptic and prime vertical, the SPASHṬA-VALANA found by adding or subtracting the ÁYANA and ÁKSHA-VALANAS (as they happen to be of the same or different denominations) is for that time at its maximum.

39. But at a point of the ecliptic distant from the point of intersection three signs either forward or backward, there is no SPASHṬA-VALANA: for, at those points the north and the south lines of the two circles are coincident.

40. However, were you to attempt to shew by the use of the versed sine, that there was then no SPASHṬA-VALANA at those points, you could not succeed. The calculation must be worked by the right sine. I repeat this to impress the rule more strongly on your mind.

Another way of refutation of using the versed sine.

41. As all the circles of declination meet at the poles; it is therefore evident that the north and south line perpendicular to the east and west line in the plane of the equinoctial, will fall in the poles.

42. But all the circles of celestial latitude meet in the pole of the ecliptic-called the KADAMBA, 24° distant from the equinoctial pole. And it is this ecliptic pole which causes and makes manifest the VALANA.

43. In the ecliptic poles always lies the north and south

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line which is perpendicular to the east and west line in the plane of the ecliptic.

To illustrate this, a circle should be attached to the sphere, taking the equinoctial pole for a centre, and 24° for radius. This circle is called the KADAMBA-BHRAMA-VṚITTA or the circle in which the KADAMBA revolves (round the pole).

The sines in this circle correspond with the sines of the declination.

All the secondary circles to the prime vertical meet in the point of intersection of the meridian and horizon, and this point of intersection is called SAMA i. e. north or south point of horizon.

Now from the planet draw circles on the sphere so as to meet in the SAMA, in the equinoctial pole and also in the ecliptic pole.

The three different kinds of VALANA will now clearly appear between these circles: viz. the ÁKSHA VALANA is the distance between the two circles just described passing through the SAMA and equinoctial pole.

2. The ÁYANA-VALANA is the distance between the circles passing through the ecliptic and equinoctial poles.

3. The SPASHṬA-VALANA is the distance between the circles passing through the SAMA and KADAMBA.

These three VALANAS are at the distance of a quadrant from the planet and are the same in all directions.

Second mode of illustrating the SPASHṬA-VALANA.

48 and 49. Or (to illustrate the subject further) making the planet as the pole of a sphere, draw a circle at 90° from it: then in that circle you will observe the ÁKSHA VALANA—which, in it, is the distance of the point intersected by the equinoctial from the point cut by the prime vertical.

The distance of the point cut by the equinoctial from that cut by the ecliptic is the ÁYANA—and the distance between the points cut by the ecliptic and prime vertical the SPASHṬA-VALANA.

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50. In this case the plane of the ecliptic is always east and west—celestial latitude forming its north and south line. Those therefore who (like S'RÍPATI or LALLA) would add the S'ARA celestial latitude to find the VALANA, labour under a grievous delusion.

51. The 1st of Capricorn and the ecliptic pole reach the meridian at the same time (in any latitude): so also with regard to the 1st Cancer. Hence at the solstitial points there is no ÁYANA-VALANA.

52. As the 1st Capricorn revolves in the sphere, so the ecliptic pole revolves in its own small circle (called the KADAMBA-BHRAMA-VRITTA round the pole).

53 and 54. When the 1st of Aquarius or the 1st of Pisces comes to the meridian, the distance in the form of a sine in the KADAMBA-BHRAMA-VRITTA, between the ecliptic pole and the meridian is the ÁYANA-VALANA. This VALANA corresponds with the KRÁNTIJYÁ or the sine of declination found from the degrees corresponding to the time elapsed from the 1st Capricornus leaving the meridian.

55. As the versed sine is like the sagitta and the sine is the half chord (therefore the versed sine of the distance of the ecliptic pole from the meridian will not express the proper quantity of VALANA as has been asserted by LALLA &c.: but the right sine of that distance does so precisely). The ÁYANA-VALANA will be found from the declination of the longitude of the Sun added with three signs or 90°.

56. Those people who have directed that the versed sine of the declination of that point three signs in advance of the Sun should be used, have thereby vitiated the whole calculation. ÁKSHA-VALANA may be in like manner ascertained and illustrated: but it is found by the right sine, (and not by the versed sine).

57. He who prescribes rules at variance with former texts and does not shew the error of their authors is much to be blamed. Hence I am acquitted of blame having thus clearly exposed the errors of my predecessors.

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58. The inapplicability of the versed sine may be further illustrated as follows. Make the ecliptic pole the centre and draw the circle called the JINA-VṚITTA with a radius equal to 24°.

Another way of refutation, of using the versed sine.

59. Then make a moveable secondary circle to the ecliptic to revolve on the two ecliptic poles. This circle will pass over the equinoctial poles, when it comes to the end of the sign of Gemini.

60. By whatever number of degrees this secondary circle is advanced beyond the end of Gemini, by precisely the same number of degrees, it is advanced beyond the equinoctial pole, in this small JINA-VṚITTA. The sine of those degrees will be there found to correspond exactly with and increase as does the sine of the declination.

61. And this sine is the ÁYANA-VALANA: This VALANA is the VALANA at the end of the DYNJYA. For the distance between the equinoctial pole and planet is always equal to the arc of which the DYNJYA is the sine i. e. the cosine of the declination.

62. But as the value of the result found is required in terms of the radius, it is consequently to be converted into those terms.

As the JINA-VṚITTA was drawn from the ecliptic pole as centre, with a radius equal to the greatest declination, so now, making the SAMA centre draw a circle round it with a radius equal to the degrees of the place's latitude. (This circle is called AKSHA-VṚITTA.)

63 and 64. To the two SAMAS or north and south points of the horizon as poles, attach a moveable secondary circle to the prime vertical. Now, if this moveable circle be brought over the planet, then its distance counted in the AKSHA-VṚITTA or small circle from the equinoctial pole will be exactly equal to that of the planet from the zenith in the prime vertical. The sine of the planet's zenith distance in the prime vertical, will, when reduced to the value of the radius of ÁKSHA-VṚITTA represent the ÁKSHA-VALANA.

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65. As in the ÁYANA-VALANA so also in this ÁKSHA-VALANA, the result at the end of the DYNJYÁ is found; this therefore must be converted into terms of the radius. From this illustration it is evident that it may be accurately ascertained from the zenith distance in the prime vertical.

66. I will show now how the ÁKSHA-VALÁNA may be also ascertained from the time from the planets being on the meridian in its diurnal circle. [The rule is as follows.] Add or subtract the S'ANKUTALA [of a given time] to and from the sine of amplitude according as they are of the same or of different denominations (for the BÁHU or BHUJA).

See verse 41, Chap. VII.

67. The sine of the latitude of the given place multiplied by the sine of the ASUS of the time from the planet's being on the meridian, and divided by the square-root of the difference between the squares of the BHUJA (above found) and of the radius, will be exactly the ÁKSHA-VALANA.*

* This rule and the means by which it has been established by BHÁSKARÁCHÁRYA require elucidation.

BHÁSKARA'CHA'RYA first directs that the BA'HU or BHUJA be found for the time of the middle of the eclipse and that a circle parallel to the prime vertical, be drawn having for its centre a point on the axis of the prime vertical distant from the centre of the prime vertical, by the amount of the BA'HU. From this as centre and the KOṬI equal to $=\sqrt{\text{rad}^2-\text{BA'HU}^2}$ as radius draw a circle parallel to the prime vertical. This circle called an UPAVṚITTA will cut the diurnal circle for the time on 2 points equally distant from the meridian. Connect those points by a chord. The half of this chord is the NATAGHAṬI'JYÁ as well in the diurnal circle as in the UPAVRITTA, but as these 2 circles differ in the magnitude, these sines will be the sines of a different number of degrees in each circle. Now the NATAGHAṬI'JYÁ is known, but it is in terms of a large circle. Reduce them to their value in the diurnal circle.

1. If TRIJYÁ : NATAJYÁ : : DYNJYA' : sine of diurnal circle.

This sine in diurnal circle is also sine in UPAVṚITTA.

2. If UPA-VṚITTA-TRIJYA : this sine : : TRIJYA equal to AKSHAJYÁ.
3. DYNJYA' : this result : : TRIJYA : sine of AKSHA-VALANA

now cancel

and there will remain the rule above stated

$$\frac{\text{NATAJYA} \times \text{AKSHAJYA'}}{\text{UPAVRITTA-TRIJYA'}} = \text{sine of AKSHA-VALANA.}$$

Here our author makes use of the diurnal circle and UPAVṚITTA in term of the equator and prime vertical, whose portions determine the VALANA. The smaller circles being parallel to the larger, the object sought is equally attained. —L. W.

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68. Or the ÁKSHA-VALANA may be thus roughly found.

Multiply the time from the planet's being on the meridian and divide the product by the half length of day, the result are the NATA degrees. The sine of these NATA degrees multiplied by the sine of the latitude and divided by the DYNJYÁ or the cosine of the declination, will give the rough ÁKSHA-VALANA.

69. Place the disc of the Sun at the point at which the diurnal circle intersects the ecliptic. The arc of the disc intercepted between these two circles represents the ÁYANA-VALANA in terms of radius of the disc.

Further illustration.

70. This VALANA is equal to the difference between the sine of declination of the centre of the Sun and of the point of intersection of the disc and ecliptic; and it is thus found; multiply the radius of disc by the BHOGYA-KHANḌA of the BHUJA of the Sun's longitude and divide by 225.

71. Then multiply this result by sine of 24° and divide by the radius: the quotient is the difference of the two sine of declination. This again multiplied by the radius and divided by the radius of Sun's disc will give the value in terms of the radius (of a great circle).

72. Now in these proportions the radius of the Sun's disc and also radius are in one case multipliers (being in third places), and in the other divisors (being the first terms of the proportion) therefore cancel both. There will then remain rule, multiply the Sun's BHOGYA KHANḌA by sine of 24° and divide by 225.

73. And this quantity is equal to the declination of a point of ecliptic 90° in advance of Sun's place. Thus you observe that the VALANA is found by the sine of declination as above alleged, (and not by the versed sine). Abandon therefore, O foolish men, your erroneous rules on this subject.

74. The disc appears declined from the zenith like an umbrella; but the declination is direct to the equinoctial pole:

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the proportion of the DYNJYÁ or complement of declination is therefore required to reduce the VALANA found to its proper value in terms of the radius.

End of Chapter VIII. In explanation of the cause of eclipses of the Sun and Moon.

CHAPTER IX.

Called DṚIKKARAMA-VÁSANÁ *on the principles of the Rules for finding the times of the rising and setting of the heavenly bodies.*

Object of the correction called the DṚIKKARMA which is requisite to be applied to the place of the planet, for finding the point of the ecliptic on the horizon when the planet reaches it.

1. A planet is not found on the horizon at the time at which its corresponding point in the ecliptic (or that point of the ecliptic having the same longitude) reaches the horizon, inasmuch as it is elevated above or depressed below the horizon, by the operation of its latitude. A correction called DṚIKKARAMA to find the exact time of rising and setting of a planet, is therefore necessary.

2. When the planet's corresponding point in the ecliptic reaches the horizon, the latitude then does not coincide with the horizon, but with the circle of latitude. The elevation of the latitude above and depression of it below the horizon, is of two sorts, [one of which is caused by the obliquity of the ecliptic and the other by the latitude of the place.] Hence the DṚIKKARAMA is two-fold, i. e. the ÁYANA and the AKSHAJA or ÁKSHA. The detail and mode of performing these two sorts of the correction are now clearly unfolded.

DṚIKKARMA.

3. When the two VALANAS are north and the planet's corresponding point in the ecliptic is in the eastern horizon, the planet is thereby depressed below the horizon by south latitude, and elevated when the planet's latitude is north.

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4. When the two kinds of VALANA are south, then the reverse of this takes place; the reverse of this also takes place when the planet's corresponding point is in the western horizon.

[And the difference in the times of rising of the planet and its corresponding point is called the resultant time of the DṚIKKARMA and is found by the following proportions.]

If radius : ÁYANA-VALANA : : what will celestial latitude give?

5. And if cosine of the latitude of the given place : ÁKSHA-VALANA : : what will SPASHṬA S'ARA give?

Multiply the two results thus found by these two proportions, by the radius and divide the products by the DYUJYÁ or cosine of declination.

6 and 7. Take the arcs of these two results (which are sines) and by the ASUS found from the sum of or the difference between these two arcs, the planet is depressed below or elevated above the horizon. The LAGNA or horoscope found by the direct process (as shown in the note on the verse 26, Chapter VII.) when the planet is depressed and by the indirect process (as shown in the same note) when it is elevated, by means of the ASUS above found, is its UDAYA LAGNA rising horoscope or the point of the ecliptic which comes to the eastern horizon at the same time with the planet.

When the planet's corresponding point is in the western horizon, the LAGNA horoscope found then by the rule converse of that above given, by means of the place of the planet added with 6 signs, is its ASTA LAGNA setting horoscope or the point of the ecliptic which is on the eastern horizon when the planet comes to the western horizon.

8 and 9. For the fixed stars whose latitudes are very considerable the resulted time of the DṚIKKARMA is found in a

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different way. Find the ascensional difference from the mean declination of the star, i. e. from the declination of its corresponding point in the ecliptic, and also from that applied with the latitude, i. e. from the true declination. The ASUS found from the sum of or the difference between the ascensional differences just found, as the mean and true declinations are of the different or of the same denominations respectively, are the ASUS of depression or elevation depending on the AKSHA DṚIKKARMA. (Find also the time depending on the ÁYANA-DṚIKKARMA) : and from the sum of or the difference between them, as they may be of the same or different denominations, the UDAYA LAGNA or ASTA LAGNA may be ascertained as above found (in the 6th and 7th verses).*

* Let A D B C be the meridian; C E D the horizon, A the zenith; E the east point of the horizon; F E G the equinoctial; K the north pole; L the south; P the planet; *p* its corresponding point in the ecliptic; H P *p* J the secondary to the ecliptic passing through the planet P, and hence *p* P the latitude. Let *f* P *g* the diurnal circle passing through the planet P and hence *p* R the rectified latitude.

Now, when the corresponding place of the planet is in the horizon, it is then evident from the accompanying figure, that the planet is elevated above or depressed below the horizon by its latitude *p* P and as it is very difficult to find the elevation or depression at once, it is therefore ascertained by means of its two parts, the one of which is from the horizon to the circle of declination, i. e. Q to R. This partial elevation or depression takes place by the planet's rectified latitude *p* R. And the other part of the elevation or depression is from the circle of declination to the circle of latitude; i. e. from R to P and this occurs by the planet's mean latitude *p* P. From the sum or difference of these two parts, the exact elevation of the planet above the horizon or the depression below it, can be determined. When the terrestrial latitude, of the given place is north and the planet's corresponding place in the ecliptic is in the eastern horizon, the A'KSHA-VALANA is then north and the circle of declination is elevated above the horizon to the north. For this reason, when the A'KSHA-VALANA is north, the planet will be elevated above the eastern horizon if its latitude be north, and if it be south, the planet will be depressed below the horizon. But the reverse of this takes place when the A'KSHA-VALANA is south which occurs on account of the south latitude of the given place, i. e. when the A'KSHA-VALANA is south, the circle of declination is depressed below the horizon to the north and hence the planet is depressed below it, if its latitude be north, and if it be south, the planet is elevated above the horizon.

Again, when the planet's longitude terminates in the six ascending signs, it is evident that the ÁYANA-VALANA becomes then north, and the north pole of the ecliptic is elevated above the circle of declination passing through the planet. Hence, when the A'YANA-VALANA is north, the planet is elevated above or depressed below the circle of declination by its mean latitude, as it is north or south. But the reverse of this takes place, when the A'YANA-VALANA is south, i. e. the planet is depressed below or elevated above the circle of declination, as its latitude is north or south. Because when the A'YANA-VALANA is south

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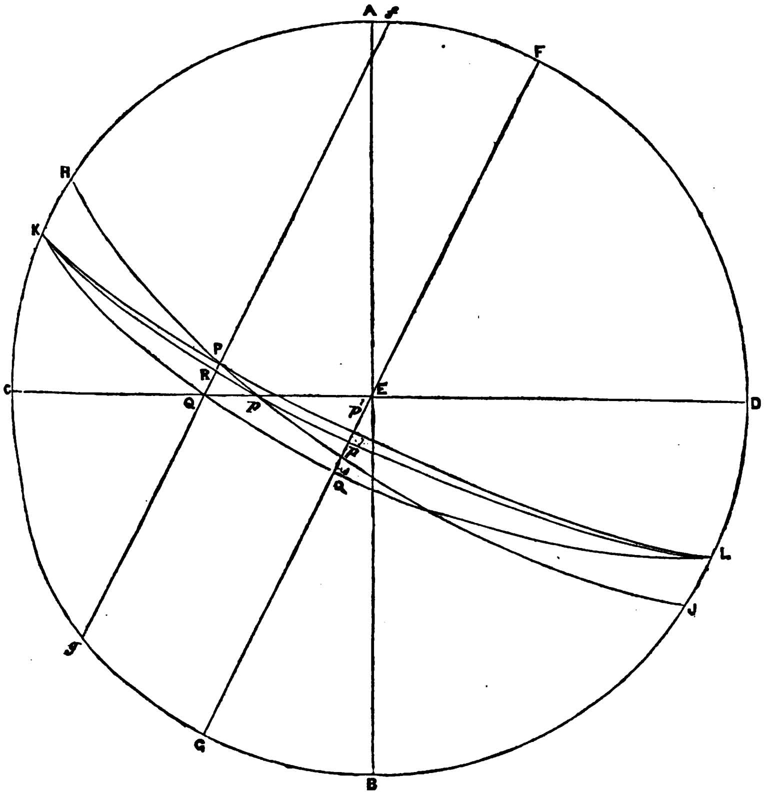

the north pole of the ecliptic lies below the circle of declination and the south above it.

Again, when the planet is in the western horizon, the circle of declination passing through the place of the planet in the ecliptic lies to the north above the horizon, but the AKSHA-VALANA, becomes south and hence the reverse takes place of what is said about the elevation or depression when the planet is in the eastern horizon. But as to the ÁYANA-VALANA, it becomes north when the longitude of the planet terminates in the ascending six signs and the north pole of the ecliptic lies below the circle of declination. Hence the depression of the planet takes place when its latitude is north and the elevation when the latitude is south. But when the longitude of the planet terminates in the discending six signs, the ÁYANA-VALANA becomes then south and the north pole of the ecliptic lies above the circle of declination. For this reason, the elevation of the planet takes place when its latitude is north, and the depression when it is south. Thus in the western horizon the elevations and depressions of the planet are opposite to those when the planet is in the eastern horizon.

Now, the time elapsed from the planet's rising when it is elevated above the horizon and the time which the planet will take to rise when it is depressed below the horizon, are found in the following manner.

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10. The [ASPASHṬA] S'ARA or true latitude [of the planet] multiplied by the DYUJYA' or cosine of declination of the point of the ecliptic, three signs in advance of the planet's corresponding point and di-

To find the value of celestial latitude in terms of a circle of declination, to render it fit to be added to or subtracted from declination.

See the figure above described in which the angle Q K R or the equinoctial arc Q′ p′ denotes the time of elevation of the planet from Q to R, and the time of elevation of the planet from R to P is denoted either by the angle P K R or by the equinoctial arc P′ p′. Out of these two times Q′ p′ and P′ p′, we show at first how to find P′ p′.

In the triangle P p R, P p = the latitude of the planet, ∠ P p R = the A'YANA-VALANA and ∠ P R p = ⌐, and

∴ R : sin P p R = sin P p : sin R P ;
or if radius
: sin of A'YANA-VALANA
= the sine of latitude
: sin R P.

Again, by the similar triangles K P R and K P′ p′
sin K P : sin R P = sin K P′ : sin P′ p′,
here, sin K P = cosine of declination and K P′ = R,

$$\therefore \sin P' p' = \frac{R \times \sin R P}{\text{cos of declination}}$$

Now, the time p′ Q′ is found as follows.

In the triangle p R Q, p R = the SPASHṬA-S'ARA which can be found by the rule given in the V. 10 of this chapter, ∠ R p Q = AKSHA-VALANA and ∠ R Q p = co-latitude of place nearly

and ∴ sin p Q R : sin R p Q : : sin p R : sin R Q
or, if cosine of latitude,
: sine of AKSHA-VALANA,
= SPASHṬA-S'ARA
: sin R Q ;
again, by the triangles K Q R, K Q′ p′;
sin K Q : sin Q R = sin K Q′ : sin p′ Q′ ;
here, sin K Q = cosine of declination and sine K Q′ = R,

$$\therefore \sin p' Q' = \frac{R \times \sin Q R}{\text{cos of declination.}}$$

If both of these times thus found, be of the elevation or both of the depression, the planet will be elevated above or depressed below the horizon in the time equal to their sum, and if one of these be that which the planet takes for its elevation and the other for its depression, the planet will be elevated above or depressed below the horizon in the time equal to their difference as the remainder is of the time of elevation or of that of the depression. The sum or difference of the two times just found is called the resulted time of the DRIK-KARMA in the S'IDDHANTAS.

That point of the ecliptic which is on the eastern horizon when the planet reaches it, is called the UDAYA LAGNA rising horoscope of the planet. As it is necessary to know this UDAYA LAGNA for finding the time of the planet's rising, we are now going to show how to find the rising horoscope. If the planet is depressed by the resulted time above mentioned, it is evident that when the planet will come to the eastern horizon, its corresponding place in the

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vided by the radius becomes [nearly] the SPASHTA or rectified latitude, [i. e. the arc of the circle of declination intercepted between the planet's corresponding point in the ecliptic and the diurnal circle passing through the planet]. This rectified latitude is used when it is to be applied to the mean declination and also in the ÁKSHA DṚIKKARMA.*

11. The celestial latitude is not reduced by BRAHMAGUPTA

ecliptic will be elevated above it by the resulted time. For this reason, having assumed the corresponding place of the planet for the Sun, find the horoscope by the direct process through the resulted time and this will be the rising horoscope. But if the planet be elevated above the horizon by the resulted time, its corresponding place will then be depressed below it by the same time when the planet will come to it. Therefore, the horoscope found by the indirect process through the resulted time ; will be the rising horoscope of the planet.

That point of the ecliptic which is on the eastern horizon when the planet comes to the western horizon, is called the ASTA LAGNA or setting horoscope of the planet. As it is requisite to know the setting horoscope for finding the time of setting of the planet, we therefore now show the way for finding the setting horoscope. If the planet be depressed below the western horizon by the resulted time, it is plane that when the planet will reaches it, its corresponding place will be elevated above it by the resulted time and consequently the corresponding place of the planet added with six signs will be depressed below the eastern horizon by the same time. Therefore, assume the corresponding place of the planet added with six signs for the Sun and find the horoscope by the indirect process, through the resulted time and this will be the ASTA LAGNA setting horoscope. But if the planet be depressed below the western horizon, its corresponding place added with six signs will then be elevated above the eastern horizon by the resulted time and hence the horoscope found by the direct process will then be the ASTA LAGNA setting horoscope.

Now the time p' Q' which is determined above through the triangle p R Q, is not the exact one, because, in that triangle the angle p Q R is assumed equal to the co-latitude of the given place, but it cannot be exactly equal to that, and consequently the time p' Q' thus determined cannot be the exact time. But no considerable error is caused in the time p' Q' thus found, if the latitude be of a planet, as it is always small. As to the star whose latitude is considerable, the time p' Q' thus found cannot be the exact time. The exact time can be found as follows.

See the preceding figure and in that take R for a star and p the intersecting point of the ecliptic, and the circle of declination passing through the star R then $p\,p'$ is called the mean declination of the star, R p, the rectified latitude and R p' the rectified declination.

Now, find the ascensional difference E p' through the mean declination $p\,p'$ and the ascensional difference E Q' through the rectified declination R p' or Q Q'. Find the difference between these two ascensional differences and this difference will be equal to p' Q' i. e. E Q'—E p' $= p'$ Q'. But it occurs then when p and R are in the same side of the equinoctial F G and when p is in one side and R in the other of the equinoctial, it is evident that p' Q' in this case will be equal to the sum of the two ascensional differences.—B. D.]

* This rule is admitted by BHÁSKARÁCHÁRYA to be incorrect; but the error being small, is neglected. Instead of using the DYUJYÁ, the YASHṬI should have been adopted.

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Omission of the last mentioned correction or reduction of Celestial latitude to its value in declination, by BRAHMAGUPTA and others.

and other early astronomers to its value in declination: and the reason of this omission, seems to have been its smallness of amount. And also it is the uncorrected latitude which is used in finding the half duration of the eclipses and in their projections &c.

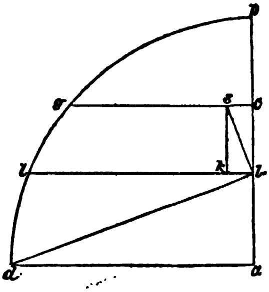
12. As the constellations are fixed, their latitudes as given in the books of these early astronomers are the SPASHAṬ-S'ARAS, i. e. the reduced values of the latitudes so as to render them fit to be added to or subtracted from the declination; and the DHRUVAS or longitude of these constellations are given, after being corrected by the ÁYANA DṚIKKARMA so as to suit those corrected latitudes that is, the star will appear to rise at the equator at the same time with longitude found by the correction.

Let *a d* be equinoctial and P the equinoctial pole,

d b = Ecliptic,
b s = Celestial latitude,
b c = Celestial latitude reduced to its value in declination is KOṬI,
s c = BHUJA being arc of diurnal circle *c s g*
s c = *k b* portion of diurnal circle of the planet's longitude at *b*.

The triangle *s c b* or *s k b* is assumed to be a DIG-VALANAJÁ TRYASRA.

The angle *s b c* = ÁYANA-VALANA or the angle of the inclination of *s b* which goes to ecliptic pole with *b c* which goes to equinoctial pole.



Hence this triangle *s b c* is called DIG-VALANAJÁ TRYSRA, the angle *s b c* varying with the ÁYANA-VALANA. If *b* were at the 1st Cancer, then the north line *a b c* which goes to the pole would go also to the ecliptic pole.

Hence the ASPASHṬA SA'RA, and SPASHṬA S'ARA of a star of 90° of latitude being both represented by *b c* would be the same. To the longitude of a star being 270°, its ASPASHṬA and SPASHṬA SÁRA would be the same.—L. W.

[The rule stated in this verse is founded upon the following principle.

Assuming the triangle *s b c* as a plane right-angled triangle and the angle *s b c*, as the declination of the point of the ecliptic three signs in advance of the planet's corresponding place, because this declination is nearly equal to the ÁYANA-VALANA, we have,

$$\sin scb : \cos sbc = bs : bc;$$

or R : YASHTI or nearly the cosine of the declination of the planet's place 9°0 + = Celestial latitude : rectified latitude.—B. D.]

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13. Those astronomers, who have mentioned that celestial latitude is an arc of a circle of declination, are stupid. Were the celestial latitude nothing more than an arc of a circle of declination, then why should they or others have ever had recourse to the ÁYANA DṚIKKARMA at all? (The planets or stars would appear on the six o'clock line at the time that the corresponding degree of the ecliptic appeared there.)

BHA'SKARA'CHÁRYA exposes the incorrect theory of certain of his predecessors, by quoting their own practice which is irreconcilable with their own theory.

14. How moreover have these same astronomers in delineating an eclipse marked off the Moon's latitude in the middle of the eclipse on SPASHṬA-VALANA-SÚTRA or on the line denoting the secondary circle to the ecliptic? and how also have they drawn perpendicularly on the VALANA-SÚTRA or the line representing the ecliptic, the latitudes of the Moon at the commencement and termination of the eclipse.

15. How moreover, have they made the latitude KOṬI, i. e. perpendicular to the ecliptic and thus found the half duration of the eclipse? If the latitude were of this nature, it would never be ascertained by the proportion (which is used in finding it).

16. A certain astronomer has (first) erroneously stated the DṚIKKARMA and VALANA by the versed sine. This course has been followed by others who followed him like blind men following each other in succession: [without seeing their way].

Censure of the astronomers who erroneously used the versed sine in the DṚIKKARMA and VALANA.

17. BRAHMAGUPTA's rule, however, is wholly unexceptionable, but it has been misinterpreted by his followers. My observations cannot be said to be presumptuous, but if they are alleged to be so, I have only to request able mathematicians to weigh them with candour.

Praise of BRAHMAGUPTA.

18. The DṚIKKARMA and VALANA found by the former astro-

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nomers through the versed sine are erroneous: And I shall now give an instance in proof of their error.

An instance in proof of the error.

19 and 20. In any place having latitude less than 24° N. multiply the sine of the latitude of the place by the radius and divide the product by the sine of 24° or the sine of the obliquity of the ecliptic and take the arc in degrees of the result found. And find the point of the ecliptic, the degrees just found in advance of the 1st Aries. Now, if from this point the planet's corresponding point on the ecliptic three signs backwards or forwards, be on the western or eastern horizon respectively, then the ecliptic will coincide with the vertical circle, and the horizon will consequently be secondary to the ecliptic. Hence the planet will not quit the horizon, though it be at a distance of extreme latitude from its corresponding point in the ecliptic [which is on the horizon], as the celestial latitude is perpendicular to the ecliptic.*

21. In this case the resulted times of the DṚIKKARMA being of exactly the same amount but one being *plus* and the other *minus*, neutralize each other [and hence there is no correction]. Now this result would not be obtained by using the versed sine—hence let the right sine (as prescribed) be always used for the DṚIKKARMA.

* [It is evident that the longitude of this point is equal to the arc through which it is found, and as the point of the ecliptic 3 signs backwards or forwards from this point is assumed on the horizon, this point therefore will at that time be the nonagesimal, and as the longitude of that point or nonagesimal is less than 90° the declination of this point will be north. This declination equals to the latitude in question. For

$\because$ The sine of the latitude of the point $= \dfrac{\text{R} \times \text{sin latitude}}{\text{sin } 24^\circ}$ (by the assumption)

$\therefore$ sin latitude $= \dfrac{\text{sin } 24^\circ \times \text{sin longitude of the point}}{\text{Radius}}$, but this $=$ sin declination.

$\therefore$ The declination of that point or nonagesimal equal to the latitude of the place. And hence, if the latitude be north the nonagesimal will be in the zenith. For this reason the ecliptic will coincide with the vertical circle.—B. D.]

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22. Again here, in like manner, it is from the two VALANAS having different denominations, but equal values, that they mutually destroy each other. By using the versed sine, they would not have equal amounts, hence the VALANAS must be found by the right sine.

[In illustration of the fact that the VALANA does not correspond with the versed sine, but the right sine BHA'SKARÁCHÁRYA gives as an example.]

23. When the Sun comes to the zenith [of the place where the latitude is less than 24°], and consequently the ecliptic coincides with the vertical circle, the SPASHṬA VALANA then evidently appears to be equal to the sine of the amplitude of the ecliptic point 90° in advance of the Sun's place in the horizon. If you, my friend, expert in spherics, can make the SPASHṬA VALANA equal to the sine of amplitude by means of the versed sine, then I will hold the VALANA found in the DHÍVṚIDDHIDA TANTRA by LALLA and in the other works to be correct.

[To this BHÁSKARA'CHÁRYA adds a further most important and curious illustration :]

24. In the place where the latitude is 66° N. when the Sun at the time of his rising is in 1st Aries, 1st Taurus, 1st Pisces, or in 1st Aquarius, he will then be eclipsed in his southern limb, because the ecliptic then coincides with the horizon. Therefore, tell me how the SPASHṬA VALANA will be equal to the radius by means of the versed sine !

[In the same manner the DṚIKKARMA calculation as it depends on the VALANA, must be made by the right sine and not by the versed sine and for the same reasons.]

Cause of error in LALLA and others, stated.

25. Even clever men are frequently led astray by conceit in their own quick intelligence, by their too hasty zeal and anxiety for distinction, by their confidence in others and by their own negligence or inadvertence, when it is thus with the wise, what need I say of fool? others, however, have said :—

26. Those given to the service of courtezans and bad poets,

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are both distinguished by their disregard of the criticisms and reflections of the world, by their breach of the rules of time and metres, and their destruction of their substance and of their subject, being beguiled by the vain delight they feel towards the object of their taste.

End of Chapter IX. called DRIKKARMA-VÁSANÁ.

CHAPTER X.

Called S'RINGONNATI-VÁSANÁ *in explanation of the cause of the Phases of the Moon.*

1. This ball of nectar the Moon being in contact with rays of the Sun, is always illuminated by her shinings on that side turned towards the Sun. The side opposite to the Sun dark as the raven black locks of a young damsel, is obscured by being in its own shadow, just as that half of a water-pot which is turned from the Sun, is obscured by its own shadow.

2. At the conjunction, the Moon is between us and the Sun: and its lower half which is then visible to the inhabitants of the earth, being turned from the Sun is obscured in darkness.

That half again of the Moon when it has moved to the distance of six signs from the Sun, appears to us at the period of full Moon brilliant with light.

3. Draw a line from the earth to the Sun's orbit at a distance of 90° from the Moon, and find also a point in the Sun's orbit (in the direction where the Moon is) at a distance equal to that of the Moon from the earth. When the Sun reaches the point just found, he comes in the line perpendicular at the Moon to that drawn from the earth to the Moon. Then the Sun illumines half of the visible side of the

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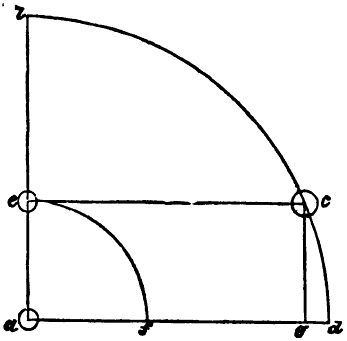
Moon. That is when the Moon is 85° . . 45′ from the Sun east or west, it will appear half full to us.*

4. The illuminated portion of the Moon gradually increases as it recedes from the Sun: and the dark portion increases as it approaches the Sun. As this sea-born globe of water (the Moon) is a sphere, its horns assume a pointed or cusped appearance (varying in acuteness according to its distance from the Sun).

5. (To illustrate the subject, a diagram should be drawn as follows). Let the distance north and south between the Sun and Moon represent the BHUJA, the upright distance between them the KOṬI and the line joining their centres the hypothenuse. The Sun is in the origin of the BHUJA which stretches in the direction where the Moon is, the line perpendicular at the end of the BHUJA is KOṬI at the extremity of which is the Moon and the line stretching (from the Moon) in the direction of the Sun is the hypothenuse. The Sun gives light (to the Moon) through the direction of the hypothenuse.

Diagram for illustrating the subject.



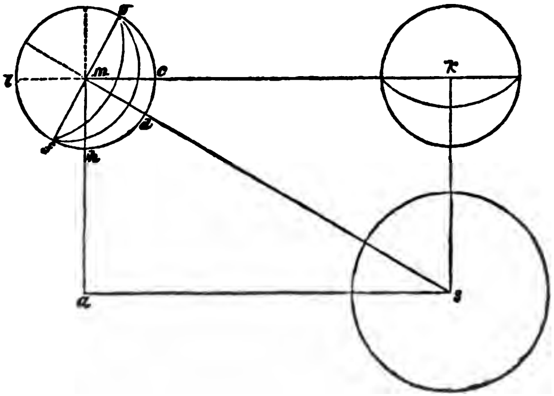
* This is thus illustrated. Let *a* represent the Earth, *b c d* the orbit of the Sun, *e f* = do. of the Moon. Then it is obvious that half of the side of the Moon visible to us will be illuminated when the Sun is at *c* and not at *d*, when the Sun is at *d* it will illumine more than half of the Moon's disc; *b c* is less than a quadrant by the arc *c d*, the sine of which *a e* or *e g* in terms of the radius of the Sun's orbit, equals to the Moon's distance from the earth. L. W.

[The arc *b c* can be found as follows:—
In the triangle *a e c* right angled at *e*, *a e* = 51566 YOJANAS, *a c* = 689377 YOJANAS according to the SIDDHA'NTAS.

Then, $\cos e\,a\,c = \frac{a\,e}{a\,c} = \frac{51566}{689377} = .0748 = \cos 85° \,..\, 43'$

$\therefore$ arc $b\,c$ = 85° .. 45′ nearly.—B. D.]

[For instance



Let S be the Sun and *m* the Moon, then *a* S = BHUJA, *a m* = KOṬI, *m* S = hypothenuse. Then *f g* a line drawn at right angles to extremity of hypotenuse will represent line of direction of the enlightened horns and the angle *h m d* opposite to BHUJA will be equal to ∠ *g m c* = the amount of angle by which the northern cusp is elevated and southern depressed,—were the Moon at *k*, there would be no elevation of either cusp either way. For the hypothenuse will also bisect the white part of the Moon. If the Sun is north of the Moon, the north cusp of the Moon is elevated: if south the southern cusp. L. W.]

[Mr. Wilkinson has extracted the following two verses from the GAṆITÁDHYÁYA.

I. When the latitude is 66° N. and the Sun is rising in 1st Aries, then the ecliptic will coincide with the horizon; now suppose the Moon to be in 1st Capricorn, then it will appear to be bisected by the meridian and the eastern half will be enlightened.

But according to BRAHMAGUPTA this would not occur, for he has declared that the KOṬI will be equal to radius in this case whereas it is obviously "nil," and it is the BHUJA which is equal to radius when there is no north and south difference

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between the Sun and Moon then the KOṬI would be equal to the hypothenuse or radius and the BHUJA would be "nil."

II.* And the Moon's horns are of equal altitude when there is no BHUJA, whilst they become perpendicular when there is no KOṬI. That the KOṬI and BHUJA shall at one and the same time be equal to radius is an obvious incompatibility. But what business have I with dwelling on the exposure of these errors? BRAHMAGUPTA' has here shown wisdom indeed, and I offer him my reverent submission !]

6. I have thus only briefly treated of the principles of the subjects mentioned in the Chapters on MADHYAGATI &c. fearing to lengthen my work; but the talented astronomer should understand the principles of all the subjects in completion, because this is the result to be obtained by a complete knowledge of the spheric.

End of Chapter X. called S'RINGONNATI-VA'SANÁ.

CHAPTER XI.

Called YANTRA'DHYA'YA, *on the use of astronomical instruments.*

Object of the Chapter.

1. As minute portions of time elapsed from sun-rise cannot be ascertained without instruments, I shall therefore briefly detail a few instruments which are of established use for this purpose.

2. The Armillary sphere, NÁDÍ-VALAYA (the equinoctial), the YASHṬI or staff, the gnomon, the GHAṬI or clepsydra, the circle, the semi-circle, the quadrant, and the PHALAKA : but of all instruments, it is "INGENUITY" which is the best.

* BHÁSKARÁCHÁRYA is here very severe on BRAHMAGUPTA who of all his predecessors is evidently his favorite, but truth seemed to require this condemnation. He at the same here does justice to A'RYA-BHATTA and the author of the SÚRYA-SIDDHA'NTA. They both justly concur in saying there is no KOṬI in this case.—L. W.

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3 and 4. (This instrument is to be made as before described, placing the BHAGOLA starry sphere, which consists of the ecliptic, diurnal circles, the Moon's path, and the circles of declination &c. within the KHAGOLA celestial sphere, which consists of the horizon, meridian, prime vertical, six o'clock line, and other circles which remain fixed in a given latitude). Bring the place of the Sun on the ecliptic to the eastern horizon: and mark the point of the equinoctial (in the BHAGOLA) intersected by the horizon, viz. east point. Having made the horizon as level as water, turn the BHAGOLA westward till the Sun throws its shadow on the centre of the Earth. The distance between the mark made on the equinoctial and the now eastern point of the horizon will represent the time from sun-rise.

Use of Armillary Sphere.

5 and 6. The LAGNA or horoscope will then be found in that point of the ecliptic which is cut by the horizon.

Take a wooden circle and divide its outer rim into 60 GHAṬIKÁS: Then place the twelve signs of the ecliptic on both sides, but instead of making each sign of equal extent, they must be made each with such variable arcs as shall correspond with their periods of rising in the place of observation (the twelve periods are to be thus marked on either side, which are to be again each subdivided into two HORÁS (or hours), three DRESHKÁṆAS, into NAVÁNS'AS or ninths of 3° . . 20′ each, twelfths of 2° . . 10′ and into TRINS'ÁNS'ÁS or thirtieths. These are called the SHAḌVARGA or six classes). These signs, however, must be inscribed in the inverse order of the signs, that is 1st Aries, then Taurus to the west or right of Aries and so on. Then place this circle on the polar axis of the KHAGOLA at the centre of the Earth (the polar axis should be elevated to the height of the pole).

The NA'DI-VALAYA.

Now find the Sun's longitude in signs, degrees, &c. for the sun-rise of the given day (by calculation) and find the same degree in the circle. Mark there the Sun's place, turn the

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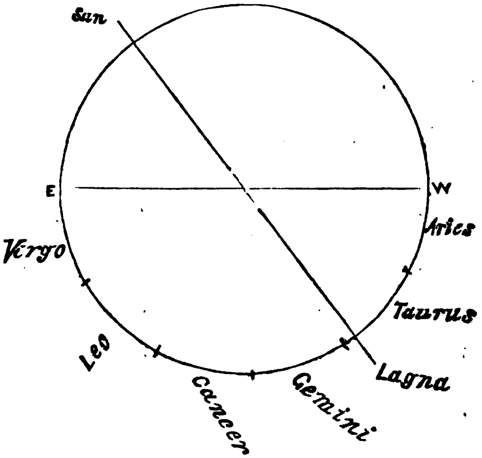
circle round the axis, so that the shadow of the axis will fall on the mark of the Sun's place at sun-rise and then fix the circle. Now as the Sun rises, the shadow of the axis will advance from the mark made for the point of sun-rise to the nadir and will indicate the hour from sun-rise, and also the LAGNA (horoscope): the number of hours will be seen between the point of sun-rise and the shadow: and the LAGNA will be found on the shadow itself. [While the Sun goes from east to west the



shadow travels from west to east and hence the signs with their periods of rising must be reversed in order—the arc from W to LAGNA represents the hour arc: and the LAGNA is at the word LAGNA in the accompanying figure.—L. W.]

7. Or, if this circle marked as above, be placed on any axis elevated to the altitude of the pole, then the distance from the shadow of the axis to the lowest part of the circle will represent the time to or from midday.

8. A GHAṬI made of copper like the lower half of a water-pot, should have a large hole bored in its bottom. See how often it is filled and falls to the bottom of the pail of water on which it is placed. Divide 60 GHAṬIS of day and night by the quotient

The GHAṬI or clepsydra.

and it will give the measure of the clepsydra. (If it is filled 60 times, then the GHAṬI will be of one GHAṬIKÁ; if 24 times it will be of one hour or 2½ GHAṬIKÁS.)

Gnomon.

9. For a gnomon take a cylindrical piece of ivory, and let it be turned on a lathe, taking care that the circumference be equal above and below. From its shadow may be ascertained the points of the compass, the place of observer, including latitude &c. and times (as has been elsewhere explained).

The CHAKRA or circle.

10. The circle should be marked with 360° on its outer circumference, and should be suspended by a string or chain moveable on the circumference. The horizon or Earth is supposed to be at the distance of three signs or 90° from the point at which it is suspended: the point opposite to that point being the zenith.

11. Through its centre put a thin axis: and placing the circle in a vertical plane, so as to catch the shadow of the Sun: the degrees passed over by the axis from the place denominated the Earth, will be altitude:

12. And the arc to the point denominated the zenith, will be that of the zenith distance.

Some former astronomers have given the following rule for making a rough calculation of the time, viz. multiply the half length of day by the obtained altitude and divide the product by the meridian altitude, the quotient will be the time sought.

To find the longitudes of planets by the circle.

13. First let the circle be so held or fixed that any two of the following fixed stars appear to touch the circumference, viz. MAGHÁ (α Leonis, Regulus), PUSHYA (δ Cancri), REVATÍ (ζ Piscium) and S'ATATÁRAKÁ (or λ Aquarii). [These stars are on the ecliptic and having no latitude, are to be preferred.] Or, that any star (out of the CHITRÁ or α Virginis Spica &c.) having very inconsiderable latitude, and the planet whose longitude is required and which is at a considerable distance from the star, appear to touch the circumference.

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14 and 15. Then look from the bottom of the circle along its plane, so that the planet appear opposite the axis; and still holding it on the plane of the ecliptic, observe also any of the above mentioned stars. The observed distance between the planet and the star, if added to the star's longitude, when the star is west, and subtracted when east of the planet, will give the planet's longitude.

Semi-circle and quadrant. The half of a circle is called a CHÁPA or semicircle. The half of a semicircle is called TURÍYA or a quadrant.

16. As others have not ascertained happily the apparent time by observations of altitudes in a vertical circle, I have therefore laboured myself in devising an instrument called PHALAKA YANTRA, the uses of which I now proceed to explain perspicuously. It contains in itself the essence of all our calculations which are founded on the true principles of the Doctrine of the Sphere.

PHALAKA-YANTRA.

17. I BHÁSKARA now proceed to describe this excellent instrument, which is calculated to remove always the darkness of ignorance, which is moreover the delight of clever astronomers and is founded on the shadow of its axis: it is also eminently serviceable in ascertaining the time, and in illustrating truths of astronomy, and therefore valued by the professors of that science. It is distinguished by having a circle in its centre. I proceed to describe this instrument after invoking that bright God of day, the Sun, which is distinguished by the epithets I have above given to the instrument viz. he is eternal and removes obscurity and cold: he makes the lotus to flower and is ever shining: he easily points out the time of the day and season and year, and makes the planets and stars to shine. He is worthy of worship from the virtuous and resides in the centre of his orb.*

Addresses to the Sun.

* This verse is another instance of the double entendre, in which even the

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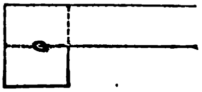
18. Let a clever astronomer make a PHALAKA or board of a plane rectangular and quadrilateral form, the height being 90 digits, and the breadth 180 digits. Let him halve its breadth and at the point thus found, attach a moveable chain by which to hold it: from that point of suspension let him draw a perpendicular which is called the LAMBA-REKHÁ.

19. Let him divide this perpendicular into 90 equal parts which will be also digits, and through them draw lines parallel to the top and bottom to the edges: these are called sines.

20. At that point of the perpendicular intersected by the 30th sine at the 30th digit, a small hole is to be bored; and in it is to be placed a pin of any length which is to be considered as the axis.

21. From this hole as centre draw a circle (with a radius of 30 digits: the circle will then cut the 60th sine), 60 digits forming the diameter. Now mark the circumference of this circle with 60 GHAṬIS and 360 degrees, each degree being subdivided into 10 PALAS.

22. Let a thin PAṬṬIKÁ or index arm with a hole at one end be made of the length of 60 digits and let it be so marked. [The breadth of the end where the hole is bored should be of one digit whilst the breadth of the whole PAṬṬIKÁ be of half digit. Let the PAṬṬIKÁ be so suspended by the pin above mentioned, that one side may coincide with the LAMBA-REKHÁ. The accompanying figure will represent the form of the PAṬṬIKÁ.



The rough ascensional difference in PALAS determined by the KHANḌAKAS or parts, being divided by 19, will here become the sine of the ascensional difference (adapted to this instrument.*)

best authors occasionally indulge. All the epithets given to the instrument apply in the original also to the Sun. This kind of double meaning of course does not admit of translation.—L. W.

* The sines of ascensional difference for each sign of the ecliptic were found by the following proportions.

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23. The numbers 4, 11, 17, 18, 13, 5 multiplied severally by the AKSHA-KARṆA and divided by 12, will be the KHANḌAKAS or portions at the given place; each of these being for each 15 degrees (of BHUJA of the Sun's longitude) respectively.

24. Now find the Sun's true longitude by applying the precession of the equinoxes to the Sun's place, and adding together as many portions as correspond to the BHUJA of the Sun's longitude above found, divide by 60 and add the quotient to AKSHA-KARNA. Now multiply the result by 10 and divide by 4 (or multiply by 2½). The quotient is here called the YASHṬI in digits and the number of digits thus found is to be marked off on the arm of the PAṬṬIKÁ counting from its hole penetrated by the axis.

25. Now hold the instrument so that the rays of the Sun shall illuminate both of its sides (to secure its being in a vertical circle): the place in the circumference marked out by the shadow of the axis is assumed to be the Sun's place.

26. Now place the index arm on the axis and putting it over the Sun's place, from the point at the end of the YASHṬI set off carefully above or below (parallel to the LAMBA-REKHÁ) on the instrument, the sine of the ascensional difference above found, setting it off above if the Sun be in the northern

1. If cosine of latitude : sine of lat. } : : what will sine of declination of 1 sign or 2 or 3 signs, give.
or as 12 : PALABHA' } : KUJYA' of 1, 2 or 3 signs.

2. If cosine of declination : this result : : what will radius : sine of ascensional difference in KALÁS.

The arc of this will give ascensional difference. This is the plain rule: but BHA'SKARA'CHA'RYA had recourse to another short rule by which the ascensional differences for 1, 2 and 3 signs, for the place in which the PALABHA' was 1 digit, were 10, 8, 3⅓ PALAS. These three multiplied by PALABHA' would give the ascensional differences with tolerable accuracy for a place of any latitude not having a greater PALABHA' than 8 digits. Now take these three PALÁTMAKAS 10, 8, 3⅓ and multiplied by six, then the PALAS of time will be reduced to ASUS. These are found with a radius of 3438: to reduce them to the value of a radius of 30 digits say,

$$\text{As } 3438 : 10 \times 6 = 60' : : 30 \text{ digits} : \frac{60 \times 30}{3438} = \text{quantity of CHARA for 1}$$

sign in this instrument, but instead of multiplying the 10 by 6 × 30 or 180 and dividing by 3438, the author taking 180 = $\frac{1}{19}$ part of 3438, divides at once by 19.—L. W.

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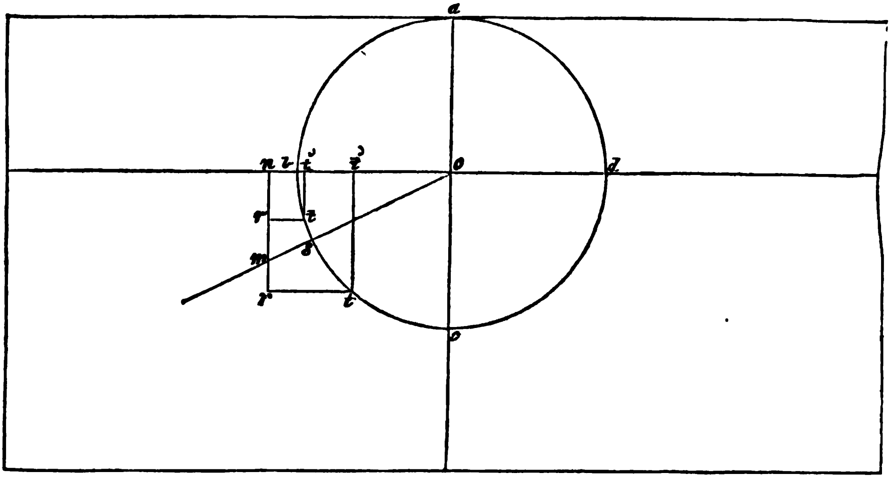
hemisphere, and below if it be in the southern hemisphere. The distance from the point where the sine which meeting the end of the sine of the ascensional difference thus set off, cuts the circle, to the lowest part of the circle will represent the GHAṬIS to or after midday.*



* In the accompanying diagram of the PHALAKA YANTRA, *o* is the centre of the circle *a b c* and the line *o s* passing through *o* is called MADHYAJYA' or middle sine. If the shadow of the pin touches the circumference in S when the instrument is held in the vertical circle passing through the Sun, S *b* will then be the zenith distance of the Sun. From this the time to or after midday can be found in the following manner.

Let a = altitude of the Sun,
d = declination,
A = ascensional difference,
l = north latitude of the place,
p = degrees in time to or after midday.

Then, we have the equation which is common in the astronomical works,

$$\cos p = \frac{R^2 . \sin a \mp R . \sin l . \sin d}{\cos l . \cos d};$$

$$= \frac{R^2 . \sin a}{\cos l . \cos d} \mp \frac{\tan l . \tan d}{R};$$

here, when the latitude is north, the second term becomes minus or plus as the declination is north or south respectively.

$$\text{But } \frac{\tan l . \tan d}{R} = \sin A \text{ or sine of ascensional difference.}$$

$$\therefore \cos p = \frac{R^2 . \sin a}{\cos l . \cos d} \mp \sin . A.$$

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27. Set off the time from midday on the instrument counting from the LAMBA-REKHÁ; from the end of the sine of this time, set off the sine of ascensional difference in a line parallel to the

To find the place of the shadow of axis from time.

Now, $\cos l : R = 12 : h$ i. e. AKSHAKARṆA (See Chapter VII. v. 45.)

$$\text{or } \frac{R}{\cos l} = \frac{h}{12},$$

$$\therefore \cos p = \frac{h}{12} \cdot \frac{R \cdot \sin a}{\cos d} \mp \sin A$$

$$= y \cdot \frac{\sin a}{R} \mp \sin A, \text{ when } y = \frac{h}{12} \cdot \frac{R^2}{\cos d}, \text{ which is called}$$

YASHṬI and can be found as follows.

$$y = \frac{h}{12} \cdot \frac{R^2}{\cos d} = \frac{R}{12} \cdot \frac{h}{12} \cdot \frac{12\ R}{\cos d},$$

$$= \frac{R}{12} \cdot \frac{h}{12} \left(12 + \frac{12 \text{ versed } d}{\cos d}\right).$$

When the BHUJA of the Sun's longitude is 15, 30, 45, 60, 75, 90, the value of $\frac{12 \text{ versed } d}{\cos d}$ is 4, 15, 32, 50, 63, 68 sixtieths respectively. The differences of these values are 4, 11, 17, 18, 13, 5 which are written in the text. Multiply these differences by h or the AKSHAKARṆA, divide the products by 12 and the quotients thus found are called the KHANḌAS for the given place. By assuming the BHUJA of the Sun's longitude as an argument, find the result through the KHANḌAS and take r for this result.

$$\text{Then } \frac{r}{60} = \frac{h}{12}\left(h + \frac{r}{60}\right),$$

$$\text{and hence, } y = \frac{R}{12}\left(h + \frac{r}{60}\right).$$

But in this instrument $R = 30$

$$\therefore y = \frac{10}{4}\left(h + \frac{r}{60}\right)$$ which exactly coincide with the rule given in the text for determining the YASHṬI.

The value of the YASHṬI will certainly be more than 30, because the value of the AKSHAKARṆA or h is more than 12.

Now, (see the diagram) suppose m is the end of the YASHṬI in the PAṬṬIKÁ or index $o\ m$ which touches the circle in S, then, in the triangle $o\ m\ n$

$$R : o\ m = \sin m\ o\ n : m\ n;$$

$$\text{or } R : y = \sin a : m\ n;$$

$$\therefore m\ n = \frac{y \times \sin a}{R};$$

$$\text{and hence, } \cos p = m\ n \pm \sin A,$$

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LAMBA-REKHÁ, but below and above according as it was to be set off above or below in finding the time from the shadow, (this operation being the reverse of the former). The sine met by the sine of ascensional difference, thus set off, is the new sine across which the PAṬṬIKÁ or index is now to be placed till the YASHṬI-CHINHA or point of YASHṬI falls on it. This position will assuredly exhibit the place of the shadow of the axis.

The Yashṭi or Staff.

28, 29 and 30. Having drawn a circle (as the horizon) with a radius equal to radius of a great circle, mark east and west points (and the line joining these points is called the PRÁCHYAPARÁ or east and west line) and mark off (from them) the amplitude at the east and west. Draw a circle from the same centre with a radius equal to cosine of declination i. e. with a radius of diurnal circle, and mark this circle with 60 GHAṬIS. Now take the YASHṬI, equal to the radius (of the great circle) and hold it with its point to the Sun, so that no shadow be reflected from it; the other point should rest in the centre. Now measure the distance from the end of the amplitude to the point of the YASHṬI when thus held opposite to the Sun. This distance applied as a chord within the interior circle will cut off, if it be before midday, an arc of the number of GHAṬIKÁs from sun-rise, and if after midday an arc of the time to sun-set.*

that is, the sine of the ascensional difference is subtracted from or added to $m\,n$ the distance between the end of the YASHṬI and the middle sine, as the Sun be in the north or the south to the equinoctial.

Again, by taking $m\,r$ equal to sin A we have,

$$\begin{aligned} \cos p &= m\,n \mp \sin A = m\,n \mp m\,r, \\ &= n\,r \text{ or } t\,t', \\ &= \cos c\,t, \\ \therefore\ p &= c\,t \text{—B. D.]} \end{aligned}$$

* [It is plain from this, that the distance from the point of the staff to the end of the amplitude is the chord of the arc of the diurnal circle passing through the Sun, intercepted between the horizon and the Sun. For this reason, the arc subtended by the distance in question in this interior circle described with a radius of the diurnal circle which is equal to the cosine of the declination, will denote the time after sun-rise or to sun-set.—B. D.]

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To find the PALABHA with the YASHṬI.

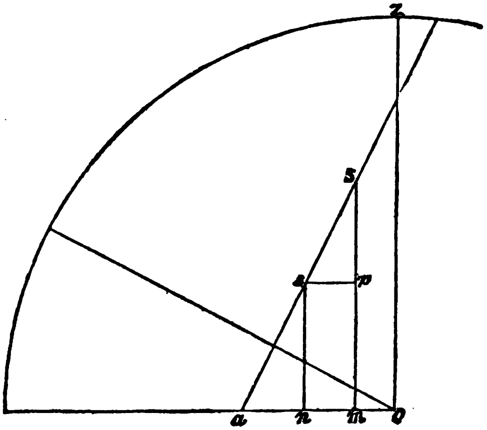
31. The perpendicular let fall from the point of the YASHṬI is the S'ANKU or sine of altitude: the place between the S'ANKU and centre is equivalent to DṚIGYÁ or sine of zenith distance. The sine of amplitude is the line between the point of horizon at which the Sun rises or sets, on which the point of the YASHṬI will rest at sun-rise and sun-set, and the east and west line the PRÁCHYAPARÁ.

32 and 33. The distance between the S'ANKU and the UDAYÁSTA-SÚTRA, multiplied by 12 and divided by the S'ANKU, will be the PALABHÁ.

Take two altitudes of the Sun with the YASHṬI: observe the S'ANKUS of the two times and the BHUJAS.

Add the two BHUJAS, if one be north and the other south, or subtract if they be both of the same denomination: multiply the above quantity (whether sum or difference) by 12 and divide by the difference of the two S'ANKUS, the result will be the PALABHÁ.* The difference between the east and west line and the root of S'ANKU is called BHUJA.

* [Let O be the east or west point of the horizon O *a*, Z the zenith, *a s* S the



diurnal circle on which S and *s* are the Sun's two places at different times and S *m* and *s n* the S'ANKUS or the sines of altitudes of the Sun, then O *m*, O *n* will be the BHUJAS, *n m* or *s p* the difference between the BHUJAS and S *p* the difference between the S'ANKUS.

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If the S'ANKU be observed three different times by the YASHṬI, then the time, declination &c. may be found (by simply observing the Sun).

To find PALABHA', declination, time, &c. from three observations by the YASHṬI, of three S'ANKUS.

34. First of all find three S'ANKUS: draw a line from the top of the first to the top of the last; from the top of the second S'ANKU, draw a line to the eastern point and a line to the western point of the horizon, so as to touch the first line drawn.

35. A line drawn so as to connect these two points in the horizontal circumference will be the UDAYÁSTA SÚTRA. The distance between it and the centre will give the sine of amplitude. The line drawn through the centre parallel to the UDYÁSTA-SÚTRA at the distance of the sine of amplitude is the east and west line.*

36. Find the PALABHÁ as before (and also the AKSHA-KARṆA). Now the sine of amplitude multiplied by 12 and divided by AKSHA-KARṆA will be the sine of declination. This again multiplied by the radius and divided by the sine of 24° or the sine of the Sun's greatest declination, will give the sine of the BHUJA of the Sun's longitude.

37 and 38. Which converted into degrees is Sun's longitude, if the observation shall have been made in the 1st quarter of the year. If in the second quarter, the longitude will be found by subtracting the degrees found from 6 signs: if

Now as the triangles $s\ a\ n$ and $S\ a\ m$ are the latitudinal triangles, the triangle $S\ s\ p$ is also the latitudinal

$\therefore\ Sp : sp = 12$: PALABHA'

$$\therefore \text{PALABHA'} = \frac{12\,sp}{Sp}.$$

It is when S, s two places of the Sun are both north or both south to the prime vertical, but when one place is north and other is south, the sum of the BHUJAS is taken.—B. D.]

* [As it is plain that the tops of the three S'ANKUS are in the plane of the diurnal circle, the line therefore drawn from the top of the first S'ANKU to that of the last, will also be in the same plane and hence the two lines touching this line, drawn from the top of the middle S'ANKU one to eastern and the other to western point of the horizon, lie in this plane. Therefore, the line joining these two points of the horizon is the intersecting line of the plane of the diurnal circle and that of the horizon, and consequently it is the UDAYA'STA SÚTRA.—B, D.]

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in the 3rd quarter, 6 signs must be added: if in the fourth quarter of the year, then the degrees found must be subtracted from 12 signs for the longitude.

The quarters of the year will be known from the seasons, the peculiarities of each of which I shall subsequently describe.

It is declared (by some former astronomers) that the shadow of the gnomon revolves on the circle passing through the ends of the three shadows made by the same gnomon (placed in the centre of the horizon), but this is wrong, and consequently the east and west and north and south lines, the latitudes &c. found by the aid of the circle just mentioned are also wrong.*

39. Whether the place of the Sun be found from the shadow or from the sine of the amplitude, it will be found corrected for precession. If the amount of precession be subtracted, the Sun's true place will be found. If the true place of the Sun be subtracted, the amount of precession will be ascertained.

The praise of instrument called DHÍYANTRA or genius instrument.

40. But what does a man of genius want with instruments about which numerous works have treated? Let him only take a staff in his hand, and look at any object along it, casting his eye from its end to the top, there is nothing of which he will not then tell its altitude, dimensions, &c. if it be visible, whether in the heavens, on the ground or in the water on the earth.

Now I proceed to explain it.

41. He who can know merely with the staff in his hand, the height and distance of a bamboo, of which he has observed the root and top, knows the use of that instrument of instruments—genius—(the DHÍYANTRA) and tell me what is there that

* The existence of such gross error in the principles of a calculation as are here referred to as existing in the works of BHA'SKARA's predecessors would seem to indicate that the science of astronomy was not of more recent cultivation than Mr. Bentley and others have maintained.—L. W.

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he cannot find out. [Here the ground is supposed to be perfectly level.]

42. Direct the staff lengthways to the north polar star; let drop-lines fall from both ends of staff, when thus directed to the star. Now the space between the two drops is the BHUJA or base of a right angled triangle, when the difference between the lines thus dropped is the KOṬI or perpendicular.

To find PALABHÁ.

43. The KOṬI multiplied by 12 and divided by the BHUJA gives the PALABHÁ.*

Having in the same way observed the root of the bamboo; [and in so doing found the BHUJA and KOṬI], multiply the BHUJA by the height of the man's eye.

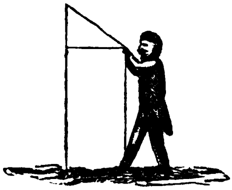
44 and 45. And divide the product by the KOṬI, the result is, you know the distance to the root of the bamboo.

To find the distance and height of a bamboo.

Having thus observed the top of the bamboo (with the staff, and ascertained the BHUJA and KOṬI), multiply the distance to the root of the bamboo by the KOṬI, and divide the product by the BHUJA, the result is the height of the bamboo above the observer's eye: this height added with the eye's height will give the height of the whole bamboo.†

For instance, suppose the staff 145 digits long, the height of observer's eye 68 digits; that in making the lower observation the BHUJA = 144 digits = 6 cubits, and KOṬI = 17 digits; that in making the observation of the top of the bamboo, the BHUJA =

Example.



* i. e. If this BHUJA : gives the KOṬI : : 12 digits of gnomon : gives the PALABHA'.

† The observer first directs *a b* his staff to *d*, the root of the tree: The staff

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116 digits and KOṬI = 87 digits. Then tell me the height of bamboo and the distance of it. As,

$$\frac{68 \times 144}{17} = 576 \text{ digits or 24 cubits distance to bamboo;}$$

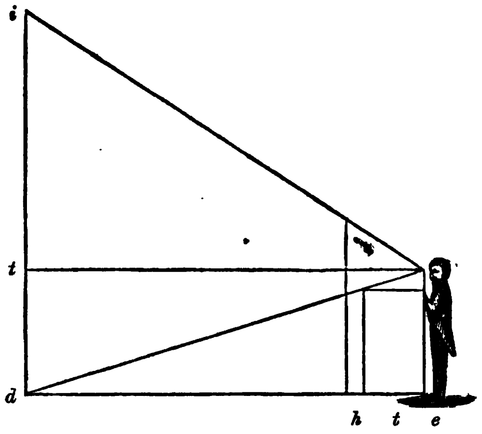
and $\dfrac{576 \times 87}{116}$ = 432 height of tree above observer's eye,

68 add the eye's height,

500 height of tree.

Let a man, standing up, first of all observe the top of an object: then (with a staff, whether it be equal to the former or not in length), let him observe again the top of the same object whilst sitting.

46. Then divide the two KOṬIS by their respective BHUJAS: take the difference of these quotients, and by it divide the difference of the heights of observer's eye—this will give the distance to the bamboo: from this distance the height of the bamboo may be found as before.*



is furnished at either end with drop lines *a h*, *b k* : *b k*—*a h* = *b c* = sin of ∠ *b a c*. Then say

As *b c* : *a c* : : *b e* : *d e* = *f b*.

He then observes the top of object and finds *g f*, which is easy, as *f b* has been found.—L. W.

* BHÁSKARA founds this rule on the following algebraic process.

47. There is a high famous bamboo, the lower part of which being concealed by houses &c. was invisible: the ground, however, was perfectly level: If you, my friend, remaining on this same spot by observing the top (first standing and then sitting), will tell me the distance and its height, I acknowledge you shall have the title of being the most skilful of observers and expert in the use of the best of instruments DHÍYANTRA.

Question.

The observer, first standing, observes the top of the bamboo and finds the BHUJA, with the first staff, to be 4 cubits or 96 digits: he then sits down and finds with another staff the BHUJA to be 90 digits. In both cases the KOṬI was one digit. Tell me, O you expert in observation, the distance of observer from the bamboo and the bamboo's height.

Example.

48. So also the altitude may be observed in the surface of smooth water: but in this case the height of observer's eye is to be subtracted to find the true height of the object:—Or the staff may be altogether dispensed with: In which last case two heights of the observer's eye (viz. when he stands and sits) will be two KOṬIS: and the two distances from the observer to the

Observation in water.

Let x = base, distance to bamboo. Then say

if $96 : 1 :: x : \frac{x}{96}$: then $\frac{x}{96} + 72$ = height of bamboo.

By second observation $90 : 1 :: x : \frac{x}{90}$, then $\frac{x}{90} + 24$ = height of bamboo.

Then $72 + \frac{x}{96} = 24 + \frac{x}{90}$; $\frac{x}{90} - \frac{x}{96} = 48$, or $\frac{6x}{8640} = 48$

$\therefore x = 69{,}120$ digits

$= 2880$ cubits.

That is $\frac{x}{90} - \frac{x}{96} = 72 - 24$

or $x = \frac{72 - 24}{\frac{1}{90} - \frac{1}{96}}$ that is difference of observer's height—difference of two KOṬIS divided by their respective BHUJA's.—L. W.

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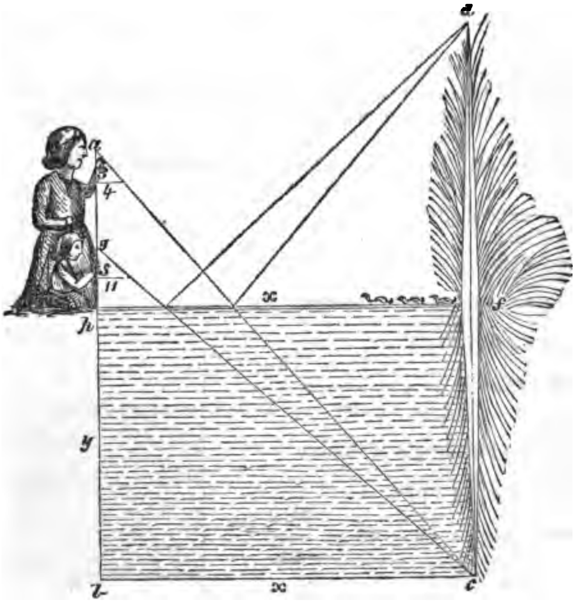
places in the water where the top of the object is reflected, the BHUJAS.

Question.

49. Having seen only the top of a bamboo reflected in water, whether the bamboo be near or at a distance, visible or invisible, if you, remaining on this same spot, will tell me the distance and height of bamboo, I will hold you, though appearing on Earth as a plain mortal, to have attributes of superhuman knowledge.

Example.

An observer standing up first observes (with his staff) the reflected top of a bamboo in water. The KOṬI = 3 digits and BHUJA = 4 digits. Then sitting down he makes a second observation and finds the BHUJA = 11 digits and KOṬI = 8 digits. His eye's height standing = 3 cubits or 72 digits, and sitting = 1 cubit or 24 digits. Tell me height of bamboo and its distance.*



* Let $d f = f c =$ height of bamboo $= h b$
then $b a$ or $y =$ height of bamboo and man's height together.
Let $b c =$ breadth of water $= x$
then by first observation

Example. A man standing up sees the shadow of a bamboo in the water—the point of the water at which the shadow appears is 96 digits off: then sitting down on the same spot he again observes the shadow and finds the distance in the water at which it appears to be 33 digits: tell me the height of the bamboo and his distance from the bamboo.*

$4 : 3 :: x : y$ or $3x = 4y$ or $x = \frac{4y}{3}$

by 2nd observation $11 : 8 :: x : y - 48$ digits

or $8x = 11y - 528$ or $x = \frac{11y - 528}{8}$

thus $x = \frac{4y}{3}$ and $x = \frac{11y - 528}{8}$

$\therefore \frac{4y}{3} = \frac{11y - 528}{8}$ or $4y = \frac{33y - 1584}{8}$

or $32y = 33y - 1584$, or $y = 1584$

$\therefore 1584 - 72 = 1512$ digits $= 63$ cubits $=$ height of bamboo.

2nd part. To find width of water or x

$$x = \frac{4y}{3} = \frac{1584 \times 4}{3} = 212 \text{ digits} = 88 \text{ cubits.—L. W.}$$

* Let $ce = 96$ digits
$cd = 33$
$ac = 72$
$bc = 24$

let $x =$ distance from observer to bamboo.

Now $ce : ac = jh : ja$

or $96 : 72 = x : y = \frac{72x}{96} = \frac{3x}{4}$

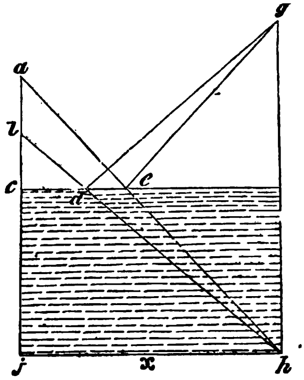
Then $\frac{3x}{4} - 3 =$ height of bamboo

Again $cd : bc :: jh : jb$

or $33 : 24 :: x : y - 48 = \frac{24x}{33}$

$= \frac{8x}{11}$

then $\frac{8x}{11} - 1 =$ height of bamboo



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50 and 51. Make a wheel of light wood and in its circumference put hollow spokes all having bores of the same diameter, and let them be placed at equal distances from each other; and let them also be all placed at an angle somewhat verging from the perpendicular: then half fill these hollow spokes with mercury: the wheel thus filled will, when placed on an axis supported by two posts, revolve of itself.

A self-revolving instrument or SWAYANVAHA YANTRA.

Or scoop out a canal in the tire of the wheel and then plastering leaves of the TÁLA tree over this canal with wax, fill one half of this canal with water and other half with mercury, till the water begins to come out, and then cork up the orifice left open for filling the wheel. The wheel will then revolve of itself, drawn round by the water.

Make up a tube of copper or other metal, and bend it into the form of an ANKUS'A or elephant hook, fill it with water and stop up both ends.

Description of a syphon.

54. And then putting one end into a reservoir of water, let the other end remain suspended outside. Now uncork both ends. The water of the reservoir will be wholly sucked up and fall outside.

55. Now attach to the rim of the before described self-revolving wheel a number of water-pots, and place the wheel and these pots like the water-wheel so that the water from the lower end of the tube flowing into them on one side shall set the wheel in motion, impelled by the additional weight of the pots thus filled. The water discharged from the pots as they reach the bottom of the revolving wheel, should be drawn

$$\frac{8x}{11} - 1 = \frac{3x}{4} - 3 \text{ or } 2 = \frac{3x}{4} - \frac{8x}{11} = \frac{x}{44}$$

$$\therefore\ x = 44 \times 2 = 88$$

Then $y = \frac{3x}{4} = \frac{3 \times 88}{4} = 3 \times 22 = 66$, height of bamboo.

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off into the reservoir before alluded to by means of a water-course or pipe.

56. The self-revolving machine (mentioned by LALLA &c.) which has a tube with its lower end open is a vulgar machine on account of its being dependant, because that which manifests an ingenious and not a rustic contrivance is said to be a machine.

57. And moreover many self-revolving machines are to be met with, but their motion is procured by a trick. They are not connected with the subject under discussion. I have been induced to mention the construction of these, merely because they have been mentioned by former astronomers.

End of Chapter XI. called YANTRÁDHYÁYA.

CHAPTER XII.

Description of the seasons,

Spring.

1. (This is the season in which) the KOKILAS (Indian black birds) amidst young climbing plants, thickly covered with gently swaying and brilliantly verdant sprouts of the mango (branches) raising their sweet but shrill voices say, "Oh travellers! how are you heart-whole (without your sweethearts, whilst all nature appears revelling) in the jubilee of spring CHAITRA, and the black bees wander intoxicated by the delicious fragrance of the blooming flowers of the sweet jasmine!"

2. The spring-born MALLIKÁ (Jasminum Zambac, swollen by the pride she feels in her own full blown beautiful flowers) derides (with disdain her poor) unadorned (sister) MÁLATI (Jasminum grandiflorum) which appears all black soiled and without leaf or flower (at this season), and appears to beckon her forlorn sister to leave the grove and garden with her

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tender budding arms, agitated by the sweet breezes from the fragrant groves of the hill of MALAYA.

3. In the summer (which follows), the lovers of pleasure and their sweethearts quitting their stone built houses, betake themselves to the solitude of well wetted cottages of the KUS'AKÁS'A grass, salute each other with showers of rose-water and amuse themselves.

The GRÍSHMA or mid-summer season.

4. Now fatigued by their dalliance with the fair, they proceed to the grove, where KÁMA-DEVA has erected the (flowering) mango as his standard, to rest (themselves) from the glare of the fierce heat, and to disport themselves in the (well shaded) waters of its BOWRIS (or large wells with steps).

5. (The rainy season has arrived, when the deserted fair one thus calls upon her absent lover :) Why, my cruel dear one, why do you not shed the light of your beaming eye upon your love-sick admirer? The fragrance of the blooming MÁLATÍ and the turbid state of every passing torrent proclaims the season of the rains and of all-powerful love to have arrived. Why, therefore, do you not have compassion on my miserable lot?*

Rainy season.

6. (Alas, cries the deserted wife, alas!) the peacocks (delighted by the thundering clouds) scream aloud, and the breeze laden with the honied fragrance of the KADAMBA comes softly, still my sweet one comes not. Has he lost all delight for the sweet scented grove, has he lost his ears, has he no pity—has he no heart?

7. Such are the plaintive accusations of the wife in the season of the rains, when the jet black clouds overspread the sky:—angered by the prolonged absence of him who reigns over her heart, she charges him, but still smilingly and sweetly, with being cruelly heedless of her devoted love.

* This is one of those verses in which a double or triple meaning is attempted to be supported; to effect this, several letters however are to be read differently. —L. W.

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8. The mountain burning with remorse at the guilt of having received the forbidden embraces of his own PUSHPAVATÍ daughter, forest appears in early autumn through its bubbling springs and streams sparkling at night with the rays of the Moon, to be shedding a flood of mournful tears of penitence.

The SÁRATKA'LA or season of early autumn.

9. In the HEMANTA season, cultivators seeing the earth smiling with the wide spread harvest, and the grassy fields all bedecked with the pearl-like dew, and teeming with joyous herds of plump kine, rejoice (at the grateful sight).

HEMANTA or early winter.

10. When the S'IS'IRA season sets in what unspeakable beauty and what sweet and endless variety of red and purple does not the 'KACHNÁR' grove unceasingly present, when its leaf is in full bloom, and its bright glories are all expanded.

S'IS'IRA or close of winter.

11. The rays of the Sun fall midday on the earth, hence in this S'IS'IRA season, they avail not utterly to drive away the cold:

*　　　*　　　*　　　*

12. Here, under the pretence of writing a descriptive account of the six seasons, I have taken the opportunity of indulging my vein for poetry, endeavouring to write something calculated to please the fancy of men of literary taste.

Sweets of poetry.

13. Where is the man, whose heart is not captivated by the ever sweet notes of accomplished poets, whilst they discourse on every subject with refinement and taste? or whose heart is not enchanted by the blooming budding beauties of the handsome willing fair one, whilst she prattles sweetly on every passing topic :—or whose substance will she not secure by her deceptive discourse?

14. What man has not lost his heart by listening to the pure, correct, nightingale-like notes of the genuine poets? or who, whilst he listens to the soft notes of the water-swans on

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the shores of large and overflowing lakes well filled with lotus flowers, is not thereby excited?

15. As holy pilgrims delight themselves, in the midst of the streams of the sacred Ganges, in applying the mud and the sparkling sands of its banks, and thus experience more than heaven's joys: so true poets lost in the flow of a fine poetic frenzy, sport themselves in well rounded periods abounding in displays of a playful taste.

End of Chapter XII.

CHAPTER XIII.

Containing useful questions called PRAS'NÁDHYÁYA.

Object of the Chapter and its praise.

1. Inasmuch as a mathematician generally fails to acquire distinction in an assemblage of learned men, unless well practised in answering questions, I shall therefore propose a few for the entertainment of men of ingenuity, who delight in solving all descriptions of problems. At the bare proposition of the questions, he, who fancies in his idle conceit, that he has attained the pinnacle of perfection, is often utterly disconcerted and appalled, and finds his smiling cheeks deserted of their colour.

2. These questions have been already put and have been duly answered and explained either by arithmetical or algebraic processes, by the pulverizer and the affected square, i. e. methods for the solutions of indeterminate problems of the first and of the second degree, or by means of the armillary sphere, or other astronomical instruments. To impress and make them still more familiar and easy I shall have to repeat a few.

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3. All arithmetic is nothing but the rule of proportion: and Algebra is but another name for ingenuity of invention. To the clever and ingenious then what is not known! I, however, write for men and youths of slow comprehension.

Praise of ingenious persons.

4. With the exception of the involution and evolution of the square and cube roots, all branches of calculation may be wholly resolved into the rule of proportion. It indeed assumes many shapes, but it is universally prevalent. All this arithmetical calculation denominated PÁṬÍ GAṆITA, which has been composed in many ways by the wisest of former mathematicians, is only for the enlightenment of simple men like myself.

5. Algebra does not consist in the letters (assumed to represent the unknown quantities): neither are the different processes any part of its essential properties. But Algebra is wholly and simply a talent and facility of invention, because the faculties of inventive genius are infinite.

6. Why, O astronomer, in finding the AHARGAṆA, do you add SAURA months to the lunar months CHAITRA &c. (which may have elapsed from the commencement of the current year): and tell me also why the (fractional) remainders of ADHIMÁSAS and AVAMAS are rejected: for you know that to give a true result in using the rule of proportion, the remainders should be taken into account.

Question 1st.

7. If you have a perfect acquaintance with the MIS'RA or allegation calculations, then answer this question. Let the place of the Moon be multiplied by one, that of the Sun by 12 and that of Mars by 6, let the sum of these three products be subtracted from three times the Jupiter's place, then I ask what are the revolutions of the planet whose place when added to or subtracted from the remainder will give the place of Saturn?

Question 2nd.

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8 and 9. In order to work this proposition in the first place proceed with the whole numbers of revolutions of the several planets in the KALPA, adding, subtracting and multiplying them in the manner mentioned in the question: then subtract the result from the revolutions of the planet given: or subtract the revolutions of the given planet from the result, according as the place of the unknown planet happen to be directed to be added or subtracted in the question. This remainder will represent the number of revolutions of the unknown planet in the KALPA. If the remainder is larger than the number from which it is to be subtracted, then add the number of terrestrial days in a KALPA, or if the remainder exceed the number of terrestrial days in the KALPA, then reduce it into the remainder by dividing it by the number of days in the KALPA.*

RULE.

* BHA'SKARA'CHA'RYA himself has given the following example in his commentary VA'SANA'-BHA'SHYA

Suppose Moon to have 4 revolutions in a KALPA of 60 days

Sun,....... 3 ....
Mars, ... 5 ....
Jupiter, ... 7 ....
Saturn, ... 9 ....

Then $4 \times 1 + 3 \times 12 + 5 \times 6 = 70$ and $7 \times 3 = 21$.
As 70 cannot be subtracted from 21 add 60 to it = 81,
Subtract 70,
remainder 11:

let p = revolutions of the unknown planet, then by the question $11 - p = 9$
or $11 - 9 = 2 = p$,
but $11 + p = 9$ or $p = 9 - 11 = 60 + 9 - 11 = 58$:

It thus appears that the unknown planet has 2 or 58 revolutions in the KALPA.

Now let us see if this holds true on the 23rd day of this KALPA:

revolutions signs *s*
for Moon, if 60 : 4 : : 23 : 6 .. 12° this $\times$ 1 = 6 .. 12°,
Sun, 60 : 3 : : 23 : 1 .. 24 this $\times$ 12 = 9 .. 18,
Mars, 60 : 5 : : 23 : 11 .. 0 this $\times$ 6 = 6 . 0

signs 10 .. 0 subtracted

Saturn, 60 : 9 : : 23 : 5 .. 12
Jupiter, 60 : 7 : : 23 : 8 .. 6 this $\times$ 3 = 0 .. 18 from
for p, 60 : 2 : : 23 : 9 .. 6 this sub. from 2 .. 18 remainder
9 .. 6

corresponding with Saturn, 5 .. 12

S

10. The algebraical learned, who knowing the sum of the additive months, subtractive days elapsed and their remainders, shall tell the number of days elapsed from the commencement of the KALPA, deserves to triumph over the student who is puffed up with a conceit of his knowledge of the exact pulverizer called SAM'SLISHṬA united, as the lion triumphs over the poor trembling deer he tears to pieces in play.

Question 3rd.

11. For the solution of this question, you must multiply the given number of additive months, subtractive days and their remainders, by 863374491684 and divide by one less than the number of lunar days in a KALPA i. e. by 1602998999999, the remainder will be the number of lunar days elapsed from the beginning of the KALPA. From these lunar days the terrestrial days may be readily found.*

RULE.

or if, 60 : 58 : : 23 : 2 : 24. Then 2 .. 24 added
to 2 .. 18

still gives Saturn's place 5 .. 12

When $p = 9 - 11$, then as 11 cannot be subtracted from 9 the sum of 60 is added to the 9. The reason for adding 60 is that this number is always be denominator of the fractional remainder in finding the place of the planets; for the proposition.

If days of KALPA : revolutions : : given days give : here the days of KALPA are assumed to be 60 hence 60 is added.—L. W.

* [When the additive months and subtractive days and their remainders are given to find the AHARGAṆA.

Let $l = 1602999000000$ the number of lunar days in a KALPA.

$e = 159300000$ the number of additive months in a KALPA.

$d = 25082550000$ the number of subtractive days in a KALPA.

$A =$ additive months elapsed.

$A' =$ their remainder.

$B =$ subtractive days elapsed.

$B' =$ their remainder.

$a =$ the given sum of the elapsed additive months, subtractive days and their remainders.

and $x =$ lunar days elapsed;

then say As $l : e : : x : A + \frac{A'}{l}$;

As $l : d : : x : B + \frac{B'}{l}$;

12. Given the sum of the elapsed additive months, subtractive days and their remainders, equal (according to BRAHMAGUPTA'S system) to 648426000171; to find the AHARGAṆA. He who shall answer my question shall be dubbed a "BRAHMA-SIDDHÁNTA-VIT" i. e. shall be held to have a thorough knowledge of the BRAHMA-SIDDHÁNTA.*

Example.

$$\therefore \text{ As } l : e + d :: x : A + B + \frac{A' + B'}{l} \text{ or } y + \frac{A' + B'}{l}$$

$$\therefore (e + d)\, x = l\, y + A' + B', \text{ or } (e + d)\, x - l\, y = A' + B',$$
$$\text{and } y = A + B;$$

$$\therefore \text{ by addition, } (e + d)\, x - (l - 1)\, y = A + B + A' + B', = a;$$

by substitution, $26675850000\, x - 1602998999999\, y = a$:
now let, $26675850000\, x' - 1602998999999\, y' = 1$,
then we shall have by the process of indeterminate problems
$x' = 863374491684$.

Again, let $m = e + d$ and $n = l - 1$,
then $m\, x - n\, y = a$; (1)
and $m\, x' - n\, y' = 1$;
$\therefore$ $a\, m\, x' - a\, n\, y' = a$,
and $m\, n\, t - m\, n\, t = 0$:
$\therefore$ $m\, (a\, x' - n\, t) - n\, (a\, y' - m\, t) = a$;
which is similar to (1);
$\therefore$ $x = a\, x' - n\, t$
$= 863374491684\, a - (l - 1)\, t$.
Hence the rule in the text.—B. D.]

* Solution. The given sum = 648426000171 and the lunar days in a KALPA = 1602999000000 :

$$\therefore \frac{648426000171 \times 863374491684}{1602998999999} = 349241932336$$ and 10300 remainder :

$\therefore$ 10300 these are lunar days elapsed.
To reduce them to their equivalent in terrestrial days says

If lunar days in a KALPA : Number of subtractive days :: Lunar days above found : 161 subtractive days and remainder amounting 267426000000.

$\therefore$ From 10300 Lunar days
subtract 161 Subtractive days

remainder 10139 Terrestrial days or AHARGAṆA.

Now to find additive months elapsed.
If lunar days in a KALPA : additive months of KALPA :: lunar days 10300 : 10 additive months and remn. 381000000000.
10 additive months = 300 lunar days.
$\therefore$ 10300 — 300 = 100,00 SAURA days elapsed.
Hence 27 years 9 months and 10 days elapsed from the commencement of KALPA.—L. W.

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13 and 14. Given the sum of the remainders of the revolutions, of the signs, degrees, minutes and seconds of the Moon, Sun, Mars, Jupiter, the S'ÍGHROCHCHAS of Mercury and Venus and of Saturn according to the DHÍVRIDDHIDA, including the remainder of subtractive days in finding the AHARGAṆA, abraded (reduced into remainder by division) by the number of terrestrial days (in a YUGA). He who, well-skilled in the management of SPHUṬA KUṬṬAKA (exact pulverizer), shall tell me the places of the planets and the AHARGAṆA from the abraded sum just mentioned, shall be held to be like the lion which longs to make its seat on the heads of those elephant astronomers, who are filled with pride by their own superior skill in breaking down and unravelling the thick mazes and wildernesses which occur in mathematical calculations.

Question 4th.

15. If the given sum abraded by the number of terrestrial days in a YUGA, on being divided by 4, leaves a remainder, then the question is not to be solved. It is then called a KHILA or an "impossible" question. If, on dividing by 4, no remainder remain, then multiply the quotient by 293627203, and divide the product by 394479375. The number remaining will give the AHARGAṆA. If the day of the week does not correspond with that of the question, then add this AHARGAṆA to the divisor (394479375) until the desired day of the week be found.*

Rule.

* [According to the DHÍVRIDDHIDA TANTRA of LALLA the terrestrial days in a YUGA = 1577917500 and the sum of all the 36 remainders for one day = 118407188600968 : this abraded by the terrestrial days in a YUGA = 259400968.
Let x = AHARGAṆA then say
As $1 : 259400968 :: x : 259400968 \times x$
This abraded by 1577917500 the terrestrial days in a YUGA will be equal to 1491227500 the given abraded sum of the 36 remainders, now
let y = the quotient got in abrading $259400968\,x$ by 1577917500, then
$$259400968\,x - 1577917500\,y = 1491227500.$$
It is evident from this that as the coefficients of x and y are divisible by 4, the given remainder 1491227500 also must be divisible by 4, otherwise the question will be impossible as stated in the text.
Hence, dividing the both sides of the above question by 4,
$$64850242\,x - 394479375\,y = 372806875 : \ldots\ldots\ldots\ldots \quad (A)$$
and let $64850242\,x' - 394479375\,y' = 1, \ldots\ldots\ldots\ldots\ldots\ldots \quad (B)$

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16. Tell me, my friend, what is the AHARGAṆA when on a Thursday, Monday or Tuesday, the 35 remainders of the revolutions, signs, degrees, minutes and seconds of the places of the planets, (the Sun, the Moon, Mars, Jupiter and Saturn and the S'ÍGHROCHCHAS of Mercury and Venus) together with the remainder of the subtractive days according to the DHÍVRID-DHIDA, give, when abraded by the number of terrestrial days in a YUGA, a remainder of 1491227500.*

Example.

17. The place of the Moon is of such an amount, that

Question 5th.

$$\frac{\text{The minutes}}{2} + 10 = \text{the seconds}$$

$$\text{the minutes} - \text{seconds} + 3 = \text{degrees}$$

$$\frac{\text{the degrees}}{2} = \text{signs.}$$

$\therefore$ $x' = 293627203$ by the processes of indeterminate problems.
Now let $a = 64850242$, $b = 394479375$, and $c = 372806875$;
$\therefore$ we have the equations (A) and (B) in the forms

$$a\,x - b\,y = c:$$
and $$a\,x' - b\,y' = 1,$$
$\therefore$ $x = c\,x' - b\,t$ (see the preceding note)
$= 293627203\,c - 394479375\,t$:
as stated in the text.—B. D.]

* Solution. The given sum of the 36 remainders in a YUGA = 1491227500 according to the DHÍVRIDDHIDA TANTRA.

$\therefore$ 1491227500 ÷ 4 = 372806875:

and $\therefore$ $\dfrac{372808875 \times 293627203}{394479375} = 277495471$ and remainder 10000 i. e. AHARGAṆA.

$\therefore$ $\dfrac{10000}{7} = 1428 - 4$ remainder, i. e. 10000 = AHARGAṆA on a Tuesday, for the YUGA commenced on Friday.

This would be the AHARGAṆA on a Tuesday.

To find the AHARGAṆA on Monday, it would be necessary to add the reduced terrestrial days in a YUGA to this 10000, till the remainder when divided by 7 was 3.

$\dfrac{10000 + 394479375 \times 2}{7} = \dfrac{788968750}{7} = 112909821 - 3$ remainder = Monday:

and $\dfrac{10000 + 394479375 \times 3}{7} = \dfrac{1183448125}{7} = 169064017 - 6$ remainder or = Thursday.—L. W.

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And the signs, degrees, minutes and seconds together equal to 130. On the supposition that the sum of these four quantities is of this amount on a Monday then tell me, if you are expert in rules of Arithmetic and Algebra, when it will be of the same amount on a Friday.*

18. Reduce the signs, degrees and minutes to seconds, adding the seconds, then reducing the terrestrial days and the planet's revolutions in a KALPA to their lowest terms, multiply the seconds of the planet (such as the Moon) by the terrestrial days (reduced) and divide by the number of seconds in 12 signs: then omitting the remainder, take the quotient and add 1 to it, the sum will be the remainder of the BHAGAṆAS revolutions.†

RULE.

* Let x = minutes

then $\frac{x+20}{2}$ = seconds

$x - \frac{x+20}{2} + 3$ = degrees.

$\frac{x - \frac{x+20}{2} + 3}{2}$ = signs

and $x + \frac{x+20}{2} + x - \frac{x+20}{2} + 3 + \frac{x - \frac{x+20}{2} + 3}{2} = 130$

$\therefore x = 58$ minutes.

$\frac{58+22}{2} = 39$ seconds.

$58 - 39 + 3 = 22$ degrees.

$\frac{22}{2} = 11$ signs.

Hence the Moon's place = 11*s*. .. 22° .. 58′ .. 39″.

† The mean place of the Moon = 11*s*. .. 22° .. 58′ .. 39″ = 1270719″
The number of seconds in 12 signs = 1296000.

Terrestrial days in a KALPA	= 1577916450000	These divided by 1650000 become DRIḌHA or reduced.	956313
Revolutions of Moon	= 57753300000		35002.

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19. The remainder before omitted subtracted from the divisor will give the remainder of seconds: if that remainder of the seconds is greater than the terrestrial days in a KALPA, then the question is an "impossible one" (incapable of solution and the planet's place cannot be found at any sun-rise): but if less it may be solved. Then from the remainder of the seconds the AHARGAṆA may be found (by the KUṬṬAKA pulverizer as given in the LÍLÁVÁTÍ and BÍJA-GAṆITA) Or,

20. That number is the number of AHARGAṆA by which the reduced number of revolutions multiplied, diminished by the remainder of the revolutions and divided by the reduced number of terrestrial days in the KALPA, will bear no remainder. The reduced number of terrestrial days in a KALPA should be added to the AHARGAṆA such a number of times as may make the day of the week correspond with the day required by the question.

Now when the mean place of the Moon was sought, the rule was

As the Terrestrial days in a KALPA : Revolutions in a KALPA :: Given days or AHARGAṆA : Revolutions.

If any remainder existed, it, when multiplied by the number of seconds in 12 signs and divided by KALPA, terrestrial days gave the Moon's mean place in seconds. We now wish to find the BHAGAṆA-S'ESHA or the remainder of revolutions, from the Moon's given place in seconds: we must therefore reverse the operation

$$\text{or } \frac{\text{Moon's place in seconds} \times \text{KALPA terrestrial days}}{\text{seconds in 12 signs}} = \text{BHAGAṆA-S'ESHA.}$$

The terrestrial days, however, to be used, must to be reduced to the lowest terms to which it, in conjunction with the KALPA-BHAGAṆAS or revolutions in a KALPA can be reduced: the lowest terms as above stated were of the terrestrial days = 956313, of the Moon's KALPA-BHAGAṆAS = 35002.

$$\therefore \frac{1270719 \times 656313}{1296000} = \frac{1215205099047}{1296000} = 937658 \text{ quotient — remainder}$$

331047.

937658 quotient
1 adding one

gives 937659 for the BHAGAṆA-S'ESHA.

The reason for adding one is, that we have got a remainder of 331047, which we never could have had, if the original remainder had been exactly 937658, it must have been 1 more. This is therefore added: but the remainder of seconds may now be found—for it will be 12963000 — 331047 = 964953.

This remainder 964953 being greater than the terrestrial days reduced to lowest terms, viz. 956313, the question does not admit of being solved.—L. W.

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21. If the Moon's BHAGAṆA-S'ESHA or the remainder after finding the complete revolutions admits of being divided by 1650000, without leaving any remainder, the question may then be solved: the reduced BHAGAṆA-S'ESHA on being multiplied by 886834 and divided by 951363, then the remainder will give the AHARGAṆA. The divisor should be added to this remainder till the day of the week found corresponds with that of the question.*

Impossible question.

22. The mean place of the Moon will never be at any sun-rise, equal to 0 signs, 5 degrees, 36 minutes and 19 seconds.

Question 6th.

23. When will the square of the ADHIMÁSA-S'ESHA remainder of the additive months, multiplied by 10 and the product increased by one, be a square: or when will the square of the ADHIMÁSA-S'ESHA decreased by one and the remainder divided by 10 be a square? The man who shall tell me at what period of the KALPA this

* [To find the AHARGAṆA from the Moon's BHAGAṆA-S'ESHA.
Let R = BHAGANA-S'ESHA,
T = 1577916450000 terrestrial days in a KALPA,
M = 57753300000 the Moon's revolutions in a KALPA,
x = AHARGANA.

Then, as T : M : : x : revolutions $+ \frac{R}{T}$ or $y + \frac{R}{T}$:

$$\therefore \quad Mx - Ty = R:$$

In this equation as M and T are divisible by 1650000, R must be divisible by the same number, otherwise the question will be KHILA or "impossible," as stated in the text.

∴ Dividing both sides of the equation by the number 1650000, we have $35002\,x - 956313\,y = R'$ or $M'\,x - T'\,y = R'$:

Now let $M'x' - T'y' = 1$: or $35002\,x' - 956313\,y' = 1$: hence we have $x' = 886834$;
and $x = R'x' - T\,t$ (see the note on the verse 11th)
$= 886834\,R' - 956313\,t$. Hence the rule in the text.

And, as the reduced BHAGAṆAS'ESHA = 937659 (see the preceding note) hence $937659 \times 886834 = 831547881606$:

This divided by 956313 will give as quotient 869555 (i. e. t) leaving a remainder of 257151 which should be the AHARGAṆA, but as the BHAGAṆAS'ESHA i. e. 937659 does not admit of being divided by 1650000 (the numbers by which the terrestrial days were reduced) it ought to have been KHILA or insoluble question: but BHÁSKARÁCHÁRYA here still stated this number to be the true AHARGAṆA.—B. D.]

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will take place—will be humbly saluted even by the wise, who generally speaking, gaze about in utter amazement and confusion at such questions, like the bee that wanders in the boundless expanse of heaven without place of rest.

Remark on the preceding question.

24. (In working questions of KUṬṬAKA pulverizer, the augment must be reduced by the same number by which the BHÁJYA dividend and HARA divisor are reduced to their lowest terms, and when the augment is not reducible by the same number as the BHÁJYA and HARA, the question is always insoluble.) But here, in working questions of KUṬṬAKA, those acquainted with the subject should know that the given augment is not to be reduced, i. e. it belongs to the reduced BHÁJYA and HARA, otherwise in some places the desired answer will not be obtained, or in others the question will be impossible.*

* [The questions in the 23rd verse are the questions of the VARGA-PRAKRITI or the affected square, i. e. questions of indeterminate problems of the second degree.

1st question. Let $a =$ the ADHIMÁSA-S'ESHA :
then by question $10\,x^2 + 1 = y^2$.

In such questions the coefficient of x is called PRAKRITI, the value of x KANISHTHA, that of the augment KSHEPA and that of y JYESHTHA.

Now assume $y = m\,x + 1$,

$$\text{then } 10\,x^2 + 1 = (m\,x + 1)^2,$$
$$= m^2\,x^2 + 2\,m\,x + 1,$$
$$\therefore \quad x = \frac{2\,m}{10 - m^2}.$$

Hence the rule given by BHÁSKARÁCHARYA in his Algebra Ch. VI., verse VI., for finding the KANISHṬHA where the KSHEPA is 1, is "Multiply any assumed number by 2 and divide by the difference between the square of the number and the PRAKRITI, the quotient will be the KANISHṬHA where the KSHEPA is 1."

Now assume $m = 3$, then $x = \dfrac{2\,m}{10 - m^2} = \dfrac{2 \times 3}{10 - 9} = 6$:

and $\therefore \quad y = \sqrt{10\,x^2 + 1} = \sqrt{361} = 19$:

$\therefore$ ADHIMÁIA-S'ESHA $= 6$.

From two sets, whether identical or otherwise, of KANISHṬHA, JYESHṬHA and KSHEPA belonging to the same PRAKṚITI, all others can be derived such as follows.

Let $a =$ PRAKRITI, and

$\left.\begin{matrix} x_1, y_1, \& \ b_1 \\ x_2, y_2, \& \ b_2 \end{matrix}\right\}$ the two sets of KANISHṬHA, JYESHTHA and KSHEPA, then we have

$$a\,x_1^2 + b_1 = y_1^2 ;$$
$$a\,x_2^2 + b_2 = y_2^2 :$$
$$\therefore \quad b_1 = y_1^2 - a\,x_1^2 ,$$
$$b_2 = y_2^2 - a\,x_2^2 :$$

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25. Tell me, O you competent in the spheric, considering it frequently in your mind for awhile, what is the latitude of the city (A) which is situated at a distance of 90° from UJJAYINÍ, and bears

Question.

$$\text{and } \therefore \quad b_1 \times b_2 = (y_1^2 - a\,x_1^2)\,(y_2^2 - a\,x_2^2),$$
$$= y_1^2\,y_2^2 - a\,x_1^2\,y_2^2 - a\,x_2^2\,y_1^2 + a\,x_1^2\,x_2^2\,;$$
$$\therefore \quad a\,x_1^2\,y_2^2 + a\,x_2^2\,y_1^2 + b_1\,b_2 = y_1^2\,y_2^2 + a^2\,x_1^2\,x_2^2 :$$
adding $\pm 2\,a\,x_1\,x_2\,y_1\,y_2$ to both sides
$$a\,x_1^2\,y_2^2 \pm 2\,a\,x_1\,x_2\,y_1\,y_2 + a\,x_2^2\,y_1^2 + b_1\,b_2 = y_1^2\,y_2^2 \pm 2\,a\,x_1\,x_2\,y_1\,y_2 + a^2 x_1^2 x_2^2.$$
$$\text{or} \quad a\,(x_1\,y_2 \pm x_2\,y_1)^2 + b_1\,b_2 = (y_1\,y_2 \pm a\,x_1\,x_2)^2 :$$
thus we get a new set of KANIṢṬHA, JYESHṬHA and KSHEPA :
i. e. new KANISHṬHA $= x_1\,y_2 \pm x_2\,y_1$;
new JYESHṬHA $= y_1\,y_2 \pm a\,x_1\,x_2$;
and new KSHEPA $= b_1\,b_2$:
Hence the Rule called BHAVANÁ given by BHÁSKARÁCHARYA in his Algebra Ch VI. verses III. & IV.

Now in the present question
$$x_1 = 6,\ y_1 = 19 \text{ and } b_1 = 1\,,$$
$$\text{and also} \quad x_2 = 6,\ y_2 = 19 \text{ and } b_2 = 1 :$$
$\therefore$ new KANISHṬHA $= 6 \times 721 + 228 \times 19 = 4326 + 4332 = 8658$;
new JYESHṬHA $= 721 \times 19 + 10 \times 6 \times 228 = 13699 + 13680 = 17379$;
and new KSHEPA $= 1 \times 1 = 1$.

Thus $x = 8658$ &c., according to the Bhávaná assumed.

The second question is
$$\frac{x^2 - 1}{10} = y^2\,,$$
$$\text{or} \quad x^2 = 10\,y^2 + 1\,.$$
Here then we have an equation similar to the former one, but x^2 is now be in the place of y^2 and y^2 in the place of x^2.
$$\therefore \quad x \text{ will be} = 19\,,$$
$$\text{or} \quad = 721 \text{ \&c.}$$
Now given ADHIMASA-SESHA as found by the first case $= 6$. The proportion by which this remainder was got, was

if KALPA SAURA days : KALPA-ADHIMASAS : : x or elapsed SAURA days
$$: y + \frac{6}{\text{KALPA SAURA days}}\,.$$
$$\therefore \text{ KALPA-ADHIMASAS} \times x = \text{KALPA SAURA days} \times y + 6$$
$$\text{or} \quad y = \frac{\text{KALPA-ADHIMASAS} \times x - 6}{\text{KALPA SAURA days}}\,.$$

From this we get a new question : "What are the integer values of x and y in this equation ?" which question is one of the questions of KUṬṬAKA and in which the coefficient of the unknown quantity in the numerator is called BHAJYA or dividend, the denominator HARA or divisor and the augment KSHEPA.

It is clear that in this equation, if the augment be not divisible by the same number as the dividend and divisor, the values of x and y will not be integers, and hence the question will be insoluble. But here in order that no question should be insoluble, the author has stated that the dividend and divisor should always be taken, reduced to their lowest terms, otherwise the question will be insoluble.

As in the present question, if the dividend KALPA-ADHIMASAS and the divisor KALPA SAURA days be taken not reduced to their lowest terms, i. e. not divided by

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due east from that city (UJJAYÍNÍ)? What is the latitude of the place (B) distant also 90° from the city (A) and bearing due west from it? What also is the latitude of a place (C) also 90° from (B) and bearing N. E. from (B): and of the place (D) which is situated at a distance of 90° from (C) and bears S. W. from (C)?*

the number 300000, the question will be an impossible one, because the augment 6 is not divisible by the same number. For this reason the dividend and divisor must be taken here reduced to their lowest terms.

Hence, dividend = reduced KALPA-ADHIMASAS $= \frac{1593300000}{300000} = 5311$; and

divisor = reduced KALPA SAURA days $= \frac{1555200000000}{300000} = 5184000$.

$\therefore$ By substitution, $y = \frac{5311\,x - 6}{5184000}$,

which gives $x = 826746$ the elapsed SAURA days or 2276 years 6 months and 6 days.—B. D.]

* Let a = the azimuth degrees,
d = the distance in degrees between the two cities,
p = PALABHA' at the given city,
k = AKSHA-KARṆA,
and x = the latitude of the other city.

Then $\sin x = \left(\frac{\sin d \times \cos a}{\text{Rad}} \pm \frac{\cos d \times p}{12}\right) \times \frac{12}{k}$.

Now in the 1st question, $a = 90°$, $d = 90°$, $p = 5$ digits, the PALABHA' at UJJAYINÍ, and $k = \sqrt{12^2 + 5^2} = 13$:

$$\therefore \sin x = \left(\frac{3438 \times 0}{3438} \pm \frac{0 \times 5}{12}\right) \times \frac{12}{13};$$

$$= (0 \pm 0) \times \tfrac{12}{13} = 0:$$

$\therefore$ $x = 0$ = latitude of (A) or of YAMAKOṬI.

(2). In the second question, $a = 90°$, $d = 90°$, $p = 0$ digits at YAMAKOṬI, and $\therefore$ $k = 12$:

$$\therefore \sin x = \left(\frac{3438 \times 0}{3438} \pm \frac{0 \times 0}{12}\right) \times \frac{12}{12};$$

$$= (0 \pm 0)\ \tfrac{12}{12} = 0:$$

$\therefore$ $x = 0$ Latitude of city (B) or LANKA.

(3). In the 3rd question, $a = 45°$, $d = 90°$, $p = 0$ at LANKÁ and $k = 12$:

$$\therefore \sin x = \left(\frac{3438 \times 2431}{3438} + \frac{0 \times 0}{12}\right) \times \frac{12}{12};$$

$$= (2431 + 0) \times 1 = 2431:$$

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26 and 27. Convert the distance of YOJANAS (between the two cities, one is given and the other is that of which the latitude is to be found,) into degrees (of a large circle), and then multiply the sine and cosine of these degrees by the cosine of the azimuth of the other city and PALABHÁ at the given city, and divide the products by radius and 12 respectively. Take then the difference between these two quotients, if the other city be south of east of the given city; and if it be north of that, the sum of the quotients is to be taken. But the reverse of this takes place, if the distance between the cities be more than a quarter of the earth's circumference. The difference or sum of the quotients multiplied by 12 and divided by AKSHAKARṆA will give the sine of the latitude sought.*

RULE.

$\therefore\ x = 45°$ Latitude of city (C).

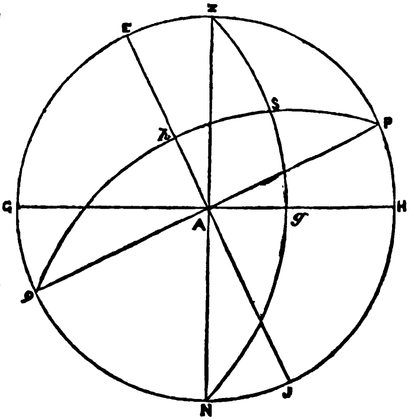
(4). In the 4th question, $a = 45°$, $d = 90°$, $p = 12$ at C and $\therefore k = 12\sqrt{2}$:

$$\therefore\ \sin x = \left(\frac{3438 \times \frac{3438}{2}\sqrt{2}}{3438} \sim \frac{0 \times 12}{12}\right) \times \frac{12}{12\sqrt{2}};$$

$$= \left(\frac{3438}{2}\sqrt{2} \sim 0\right) \times \frac{1}{\sqrt{2}} = \frac{3438}{2};$$

$\therefore\ x = 30°$ Latitude of D.—L. W.

* [Let Z be the Zenith of the given city bearing a north latitude, Z H N G the Meridian, G A H the Horizon, P the north pole, S the Zenith of the other city, the latitude of which is to be found and Z S N the azimuth circle passing through S. Then the arc Z S (which is equal to the distance in degrees between the two cities) will be the Zenith distance of S; the arc H G, the arc containing the given azimuth degrees, and S h which is equal to the declination of the point S, the latitude of the other city which can be found as follows.



Let $a = \mathrm{H}\,g$ the given azimuth degrees,

$d = $ Z S the distance in degrees between the two cities,

$p = $ PALABHA,

$k = $ AKSHA-KARṆA

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28. Tell me quickly, O Astronomer, what is the latitude of a place (A) which is distant $\frac{1}{8}$ of the earth's circumference from the city of DHÁRÁ and bears 90° due east from it? What also is the latitude of a place distant 60° from DHÁRÁ, but bearing 45° N. E. from it? What also is the latitude of a place distant 60° from DHÁRÁ and bears S. E. from it? What also are the latitudes of three places 120° from DHÁRÁ and bearing respectively due east, N. E., and S. E. from it?*

Question.

and $x = S\,h$ the declination of the point S i. e. the latitude of the other city.

Then say, As sine Zg : sine Ag : : sine Z S : the BHUJA i. e. the sine of distance from S to the Prime Vertical.

or R : cos a : : sin d : BHUJA

$$\therefore \text{BHUJA} = \frac{\cos a \sin d}{R}.$$

And by similar latitudinal triangles, 12 : p : : cos d : S'ANKUTALA,

$$\therefore \text{S'ANKUTALA} = \frac{p \times \cos d}{12}.$$

Now when the other city is north of east of the given city, it is evident that the BHUJA will be north and consequently

the sine of amplitude = BHUJA + S'ANKUTALA :

but when the other city is south, the BHUJA also will be south and then, the sine of amplitude = BHUJA ∼ S'ANKUTALA,

$$\text{or the sine of amplitude} = \frac{\cos a \times \sin d}{R} \pm \frac{p \cos d}{12}.$$

And by latitudinal triangles

k : 12 : : sine of amplitude : sine of declination i. e. sin x

$$\therefore \sin x = \frac{12 \times \text{sine of amplitude}}{k} = \frac{12\left(\frac{\cos a \times \sin d}{R} \pm \frac{p \times \cos d}{12}\right)}{k},$$

hence the rule in the text.

If the distance in degrees between the two cities be more than 90°, the point S will then lie below the Horizon, and consequently the direction of the BHUJA will be changed. Therefore the reverse of the signs ± will take place in that case.—B D.]

* Here also $\sin x = \left(\frac{\sin d \times \cos a}{R} \pm \frac{\cos d \times p}{12}\right) \times \frac{12}{k}$.

(1.) In the first question, $a = 90°$, $d = 60°$, $p = 5$ digits the PALABHA of DHARA and ∴ $k = 13$.

$$\therefore \sin x = \left(\frac{2977 \times 0}{3438} + \frac{1719 \times 5}{12}\right) \times \frac{12}{13};$$

$$= \frac{1719 \times 5}{12} \times \frac{12}{13} = \frac{8595}{13} = 662\,\frac{9}{13}:$$

29. Tell me, my friend, quickly, without being angry with me, if you have a thorough knowledge of the spheric, what will be the PALABHÁ of the city where the Sun being in the middle of the ARDRÁ NAKSHATRA (i. e. having the longitude 2 signs 13° 20′) rises in the north-east point.*

Question.

$\therefore\ x = 11^\circ..15'..1''$ Latitude of city due east from DHARA.

(2). In the 2nd equation, $a = 45^\circ$, $d = 60^\circ$, $p = 5$ & $\therefore\ k = 13$:

$$\therefore\ \sin x = \left(\frac{2977 \times 2431}{3438} \times \frac{1719 \times 5}{12}\right) \times \frac{12}{13};$$

$$= \frac{19399109}{7449} = 2604\,\frac{1913}{7449};$$

$\therefore\ x = 49^\circ\ .\ 18'..24''$ Latitude of city bearing 45° N. E. from DHARA.

*(3). In the 3rd question, $a = 45^\circ$, $d = 60^\circ$, $p = 5$ and $k = 13$.

$$\therefore\ \sin x = \left(\frac{2977 \times 2431}{3438} \sim \frac{1719 \times 5}{12}\right) \times \frac{12}{13};$$

$$= \frac{9549239}{7449} = 1281\,\frac{7070}{7449}.$$

$\therefore\ x = 21^\circ..54'..34''$ Latitude of city bearing the S. E. from DHARA.

(4). To find latitude of place 120° from DHARA and due east. Here, $\sin d = \sin 120^\circ = \sin 60^\circ = 2977$, $\cos d = \cos 120^\circ = -\sin 30^\circ = -1719$ $\cos a = 0$, $p = 5$ and k 13 :

$$\therefore\ \sin x = \left(\frac{2977 \times 0}{3438} \pm \frac{1719 \times 5}{12}\right) \times \frac{12}{13};$$

$$= 662\,\frac{9}{13}:$$

$\therefore\ x$ or latitude $= 11^\circ\ .\ 15'..1''$.

The latitudes of the places 120° bearing N. E. & S. E., will be the same as the latitudes of those places distant 60° and bearing S. E & N. E. Hence the latitudes are 21° . 54′..34″ and 49° 18′ 24″.—L. W.

* *Ansr.* Sun's amplitude = sine of 45° = 2431′, the sine of longitude of middle of ARDRA = sine of 2 signs 13° 20′ = sin 73° 20′ = 3292′..6″ 40‴ and the sine of the Sun's greatest declination = sin 24° = 1397′.

Then say : As Rad : sin 24° : : sin (73° 20′) : sine of declination, and as sine of amplitude : sine of declination : : Rad : cos of latitude,

$\therefore$ sine of amplitude : sin 24° : : sin (73° 20′) : cos of latitude.

$$\therefore\ \text{cos of latitude} = \frac{\sin 24^\circ \times \sin (73^\circ..20')}{\text{sine of amplitude}} = \frac{1397' \times (3292'..6''..40''')}{2431'}$$

$= 1891'\ 50'\ 48'' =$ sine of 33° 23′ 37″ :

whence latitude will be 56° 36′ 23′ $\therefore$ sine of latitude = 2870′ 13″.

Then say : As cos of latitude : sine of latitude : : Gnomon : equinoctial shadow
1891′..51″ : 2870′ 13″ : : 12

$$\therefore\ \text{equinoctial shadow} = \frac{12 \times (2870'..13'')}{1891'\ 51''} = 18\,\frac{13}{60}\ \text{digits.—L. W.}$$

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30. Tell me the several latitudes in which the Sun remains above the horizon for one, two, three, four, five and six months before he sets again.*

Question.

31. If you, O intelligent, are acquainted with the resolution of affected quadratic equations, then find the Sun's longitude, observing that the sum of the cosine of declination, the sine of declination, and the sine of the Sun's longitude: equal to 5000 is (the radius is assumed equal to 3438.)

Question.

32. Multiply the sum of the cosine of declination, the sine of declination, and the sine of Sun's longitude by 4, and divide the product by 15, the quotient found will be what has been denominated the ÁDYA. Next square the sum and double the square and divide by 337, the quotient is to be substracted from 910678. Take the square-root of the remainder. That root must then be subtracted from the ADYA above found: the remainder will be the declination, when the radius is equal to 3438. From the declination the Sun's longitude may be found.†

RULE.

* *Ansr.* When the Sun has northern declination he remains above the horizon for one month in 67° N. L.

two months in 69°
three months 73°
four months 78°
five months 84°
six months 90°

These are roughly wrought: for BHASKARÁCHÁRYA'S rule for finding these Latitudes see the TRIPRAS'NADHYAYAS of the GOLADHYAYA and also the GANITADHYAYA.—L. W.

† [Let $a =$ the given sum,
$p =$ the sine of the Sun's extreme declination
$x =$ the sine of the Sun's declination.

Then the cosine of declination will be $\sqrt{R^2-x^2}$ and the sine of the Sun's longitude $= \frac{R\,x}{p}$:

$$\therefore \text{ by question } \sqrt{R^2-x^2} + x + \frac{R\,x}{p} = a:$$

$$\text{or} \quad p\sqrt{R^2-x^2} + (R+p)\,x = a\,p,$$

$$\text{and} \quad p\sqrt{R^2-x^2} = a\,p - (R+p)\,x;$$

$$\therefore R^2 p^2 - p^2 x^2 = a^2 p^2 - 2\,a\,p\,(R+p)\,x + (R^2 + 2\,R\,p + p^2)\,x^2;$$

$$\therefore (R^2 + 2\,R\,p + 2\,p^2)\,x^2 - 2\,a\,p\,(R+p)\,x = -(a^2 - R^2)\,p^2;$$

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33. Given the sum of the sines of the declination and of the altitude of the Sun when in the prime vertical; the TADDHRITI, the KUJYÁ and sine of amplitude equal to 9500, at a place where the PALABHÁ

Question.

or $$x^2 - \frac{2ap(R+p)}{R^2+2Rp+2p^2}x = -\frac{(a^2-R^2)p^2}{R^2+2Rp+2p^2};$$

completing the square, $$x^2 - \frac{2ap(R+p)}{R^2+2Rp+2p^2}x + \frac{a^2p^2(R+p)^2}{(R^2+2Rp+2p^2)^2}$$
$$= \frac{a^2p^2(R+p)^2}{(R^2+2Rp+2p^2)^2} - \frac{(a^2-R^2)p^2}{R^2+2Rp+2p^2};$$
$$= \frac{R^4p^2+2R^3p^3+2R^2p^4-a^2p^4}{(R^2+2Rp+2p^2)^2};$$
$$= \frac{R^2p^2}{R^2+2Rp+2p^2} - \frac{a^2p^4}{(R^2+2Rp+2p^2)^2}:$$

$$\therefore x - \frac{ap(R+p)}{R^2+2Rp+2p^2} = \pm\sqrt{\frac{R^2p^2}{R^2+2Rp+2p^2} - \frac{a^2p^4}{(R^2+2Rp+2p^2)^2}}:$$

or $$x = \frac{ap(R+p)}{R^2+2Rp+2p^2} \pm \sqrt{\frac{R^2p^2}{R^2+2Rp+2p^2} - \frac{a^2p^4}{(R^2+2Rp+2p^2)^2}}.$$

Now here $R = 3438$ and $p = 1397$,

$$\therefore \frac{ap(R+p)}{R^2+2Rp+2p^2} = \frac{ap(R+p)}{(R+p)^2+p^2} = \frac{a\times 1397\times 4835}{(4835)^2+(1397)^2} = \frac{6734495\,a}{25328834} =$$
$\frac{4}{15}a$ nearly = ÁDYA;

$$\frac{a^2p^4}{(R^2+2Rp+2p^2)^2} = \frac{3808777688881\,a^2}{641549831799556} = \frac{2\,a^2}{337} \text{ nearly};$$

and $$\frac{R^2p^2}{R^2+2Rp+2p^2} = \frac{23067713928996}{25328834} = 910729,$$ in place of this the Author has taken the number 910678.

$\therefore x =$ ÁDYA $\pm\sqrt{910678 - \frac{2}{337}a^2}$:

but of these, the positive value is excluded by the nature of the case, because the sine of declination is always less than 1397.

Hence the Rule in the text.

Solution. The given sum = 5000,

$\therefore$ ÁDYA $= \frac{5000\times 4}{15} = 1333'\ 20''$ and $\frac{2}{337}a^2 = 148367'\ 57''\ 9.'''$

$\therefore$ sine of declination $= 1333'\ 20'' - \sqrt{910678 - 148367'\ 57'\ 9'''}$
$= 1333'\ 20'' - 873'\ 6'\ 13'''$
$= 460'\ 13''\ 47'''$: from which we have the longitude of he Sun = $0^s..19^\circ..14'\ 36''$ or $5^s..10^\circ..45'\ 24''$ or $6^s\ 19^\circ\ 14'..36''$ or $11^s..10^\circ..45'..24''$.—B. D.]

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or equinoctial shadow is 5 digits, tell me then, my clever friend, if quick in working questions of latitudinal triangles and capable of abstracting your attention, what are the separate amounts of each quantity ?

34. First assume the sine of declination to be equal to 12 times the shadow PALABHÁ: and then find the amounts of the remaining quantities upon this supposition. Then these on the supposition made, multiplied severally by the given sum and divided by their sum on the supposition made, will respectively make manifest the actual amounts of those quantities the sum of which is given.*

Rule.

35. If you have a knowledge of mathematical questions involving the doctrine of the sphere, tell me what will be the several amounts of sines of amplitude, declination and the KUJYÁ (where the PALABHÁ is 5 digits) when their sum is 2000.†

Question.

* Solution. Here PALABHÁ = 5 digits

∴ Suppose the sine of declination = 5 × 12 = 60:

and then say. If PALABHÁ : AKSHAKARṆA : : sine of decln. : SAMA S'ANKU

or 5 : 13 : : 60 : SAMA S'ANKU $= \frac{13 \times 60}{5} = 156$,

Gnomon : AKSHAKARṆA : : SAMA S'ANKU : TADDHRITI $= \frac{156 \times 13}{12} = 169$,

12 : PALABHA' : : sine of decln. : KUJYA $= \frac{60 \times 5}{12} = 25$,

and 12 : AKSHAKARṆA : : sine of decln. : sine of amplitude $= \frac{60 \times 13}{12} = 65$.

∴ If the sum : sine of decln. supposed : : given sum : sine of decln. required.

or 475 : 60 : : 9500 : 1200.

If 475 : 156 : : 9500 : 3120 SAMA S'ANKU required.

and so on 3380 TADDHRITI

500 KUJYA

1300 sine of amplitude.

Ansr.

L. W.

† Solution. Here also PALABHA = 5,

then suppose sine of declination as before = 60,

and ∴ sine of amplitude = 65,

and KUJYA = 25,

the sum = 150,

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36. But dropping for a moment those questions of the SIDDHÁNTAS involving a knowledge of the doctrine of the sphere, tell me, my learned friend, why in finding the point of the ecliptic rising above the horizon at any given time, (that is the LAGNÁ or horoscope of that time,) you first calculate the Sun's apparent or true place for that time, i. e. the Sun's instantaneous place: and further tell me, when the Sun's SÁVANA day, i. e. terrestrial day, consists of 60 sidereal GHAṬIKÁS and 10 PALAS, the LAGNA calculated for a whole terrestrial day should be in advance of the Sun's instantaneous place, and the LAGNA calculated for the time equal to the terrestrial day *minus* 10 PALAS should be equal to the Sun's instantaneous place.

Questions.

37. Are the GHAṬIKÁS used in finding the LAGNA, GHAṬIKÁS of sidereal or common SÁVANA time? If they are SÁVANA GHAṬIKÁS, then tell me why are the hours taken by the several signs of the ecliptic in rising, i. e. the RÁS'YUDAYA which are sidereal, subtracted from them, being of a different denomination? If on the other hand you say they are sidereal, then I ask why, in calculating the LAGNA for a period equal to a whole SÁVANA day i. e. 60 sidereal GHAṬIKAS and 10 PALAS, the LAGNA does not correspond with, but is somewhat in advance of, the Sun's instantaneous place; and then why the Sun's instantaneous place is used in finding the LAGNA or horoscope.*

38. Given the length of the shadow of gnomon at 10 GAṬÍS after sun-rise equal to 9 digits at a place where the PALABHÁ in 5 digits: tell me what is the longitude of the Sun, if you are *au fait* in solving questions involving a knowledge of the sphere.†

Question.

Then say as before

as	150	:	60	: :	2000	:	800 sine of declination,
as	150	:	65	: :	2000	:	866⅔ sine of amplitude,
as	150	:	25	: :	2000	:	333⅓ KUJYA.—L. W.

* [For answers to these questions see the note on the 27th verse of the 7th Ch.—B. D.]

† [For solving this question, it is necessary to define some lines drawn in the Armillary sphere and shew some of their relations.

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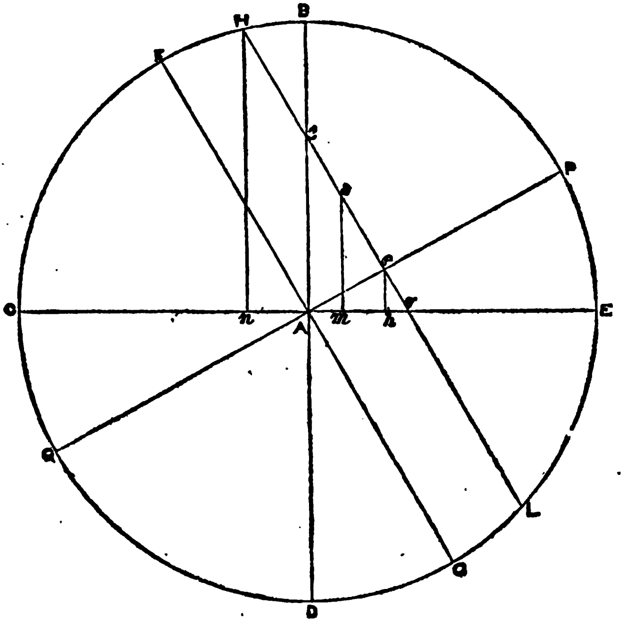
39. Tell me, O Astronomer, what is the PALABHÁ at that place where the gnomon's shadow falling due west is equal to the gnomon's

Question.



Let B C D E be meridian of the given place, C A E the diameter of the Horizon, B the Zenith, P and Q tne north and south poles, B A D the diameter of the Prime Vertical, F A G that of the Equinoctial, P A Q that of the six o'clock line, H *f* L that of one of the diurnal circles, *s* the Sun's projected place in it and *f h*, *s m*, H *n* perpendiculars to C E. Then

B F or E P = the latitude of the place,

A *f* = the sine of the Sun's declination,

A *g* = AGRA or the sine of amplitude,

f g = KUJYA'. (It is called CHARAJYA' or sine of the ascensional difference when reduced to the radius of a great circle.)

f s = KALA'. (It is called SÚTRA when reduced to the radius of a great circle.)

s g = IṢHṬA HṚITI. (It is called TADDHRITI when *s* is at *e*, HṚITI when *s* is at H and KUJYA when *s* is at *f*.)

The ISHṬA HṚITI reduced to the radius of a great circle is called ISHṬA ANTYA', but *s* coincides with H, it is called ANTYA' only.

It is evident from the figure above described that

(1) ISHṬA HṚITI = KALA' ± KUJYA',

(2) ISHTA ANTYA' = SÚTRA ± CHARAJYA',

(3) HṚITI = DYUJYA' or cosine of declination ± KUJYA',

(4) ANTYA' = radius ± CHARAJYA'.

Here the positive or negative sign is to be taken according as the Sun is in the northern or southern hemisphere.

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height when the Sun is in the middle of the sign Leo, i. e. when his longitude is 4 signs and 15 degrees.*

Now at a given hour of the day, the ISHṬA HṚITI and others can be found as follows.

Half the length of the day diminished by the time from noon (or the NATA KA'LA properly so called) is the UNNATA KALA (or elevated time). Subtract from or add to the UNNATA KA'LA the ascensional difference according as the Sun is in the northern or southern hemisphere: reduce the remainder to degrees: the sine of the degrees is SÚTRA. The SÚTRA multiplied by the cosine of declination and divided by the radius gives the KALA'. Then from the above formulæ we can easily find the ISHṬA HṚITI and others.

Now to find the answer to the present question.

Square the length of the Gnomonic shadow and add it to the square of the Gnomon or 144: and square-root of the sum is called the hypothenuse of the shadow. From this hypothenuse find the MAHA'S'ANKU or the sine of the Sun's altitude by the following proportion.

As the hypothenuse of the shadow
: Gnomon or 12
: : Radius
: The MAHAS'ANKU or the sine of the Sun's altitude.

Then by similar latitudinal triangles,
as the Gnomon of 12 digits
: AKSHA KARṆA found from given PALABHA'
: : MAHAS'ANKU
: ISHṬA HṚITI (see verses from 45 to 49 of the 7th Chapter).

Reduce the given UNNATA KA'LA to degrees and assume the sine of the degrees as ISHṬANTYA (for this will always be very near to the ISHṬA'NTYA). Then

$$\frac{\textit{cosine of declination}}{\text{Radius}} = \frac{\text{ISHTA HṚITI}}{\text{ISHṬA'NTYA}}$$

From this the cosine of declination will nearly be found, and thence the declination and ascensional difference can also be found. From the ascensional difference, just found, find the ISHṬA'NTYA' of two kinds, one when the Sun is supposed to be in the northern hemisphere and the other when the Sun is supposed to be in the southern hemisphere. Of these two ISHṬANTYA'S that is nearly true which is nearer to the rough ISHṬA'NTYA' first assumed (i. e. the sine of the UNNATA KA'LA). From this new ISHṬA'NTYA' find again the declination and repeat the process until the roughness of declination vanishes. From the declination, last found, the longitude of the Sun can be found.—B. D.]

* The hypothenuse of the shadow is first to be found. Then say
As hypothenuse of the shadow
: Gnomon
: : Rad
: the MAHA' S'ANKU or the sine of the Sun's altitude.

Here we shall find sine of 45°. This is the SAMA S'ANKU.
It is 2431'

Sine of declination of the Sun when in 4 signs .. 15° = 987' 48"

$\therefore \overline{2431'}^2 - \overline{987' .. 48''}^2 = (\text{TADDHṚITI} - \text{KUJYA}')^2$

or 5909761 — 975749 .. 9 = 4934011 . 51.

$\therefore \text{TADDHṚITI} - \text{KUJYA}' = \sqrt{4934011 .. 51} = 2221' .. 15''$

Here we have 3 sides of the latitudinal triangle consisting SAMA S'ANKU, declination and TADDHṚITI — KUJYA'. Hence we may find the latitude.

Then by similar latitudinal triangles
As TADDHṚITI — KUJYA' 2221' .. 15'
: sine of declination 987' .. 48"
: : Gnomon 12
: PALABHA' 5⅓ digits.—L. W.

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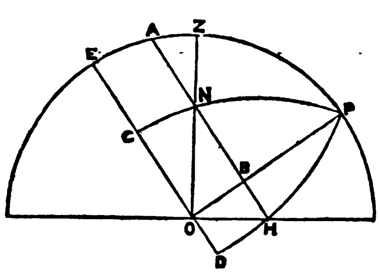
40. When the Sun enters the prime vertical of a person at UJJAYINÍ either at 5 GHATIS after sun-rise or 5 GHATIS before or after midday, what are his declinations? If you will answer me this I will hold you to be the sharp ANKUS'A (goad) for the guidance of the intoxicated elephants, the proud astronomers.*

Question.



* First of all assume H N the TADDHṚITI = sine of the given elevated time that is = sin 30°. From this find the S'ANKU or the sine of altitude by similar triangles.

If AKSHA KARṆA or hypothenuse of equinoctial shadow.

: Gnomon 12

: : TADDHRITI

$$\therefore \text{SAMA S'ANKU} = \frac{12 \times \text{TADDHRITI}}{13} = \text{O N}$$

From O N, to find O B the sine of declination say

as AKSHA KARṆA : PALABHA′ : : O N : O B $= \dfrac{\text{PALABHA}' \times \text{O N}}{13}$ = sine of declination.

From O B we may now find the longitude of the Sun and O D the ascensional difference: Now deduct this ascensional difference from the sine of elevated time converted into degrees. Hence

$$\text{C D} - \text{O D} = \text{C O}.$$

Now reduce C O to terms of a small circle on the supposition that the Sun has the declination now found.

As Rad : C O : : cosine of declination : N B.

Now find also B A by the same proportion.

Then N B + B A = N H′ a new value of TADDHRITI.

If H N : gave O B : : H N′ : O B′ corrected value of O B.

Hence a corrected longitude of the Sun.

The operation to be repeated till rightness is found.

2nd.—To find the declination from the NATA KA′LA or time from noon = sin 30°.

Let a = the sine of NATA KA′LA : $R^2 - a^2 = \text{SÚTRA}^2$,

and x = the sine of declination : $R^2 - x^2 = \cos^2$ of declination.

The SÚTRA reduced to value of diurnal circle will give KALA′

The proportion is. As R : SÚTRA : : cos of declination : KALA′,

but I do not know what cos of declination is but only its square.

I must therefore make this proportion in squares

As R^2 : SÚTRA^2 : : cos^2 of declination : $\overline{\text{KALA}}\rceil^2 = \dfrac{(R^2 - a^2)(R^2 - x^2)}{R^2}$

Now by similar latitudinal triangles

As $\overline{12}\rceil^2 : \overline{\text{PALABHA}'}\rceil^2 : : \overline{\text{KALA}}\rceil^2$: sine^2 of declination

$$\therefore \text{sine}^2 \text{ of declination} = \frac{\overline{\text{PALABHA}}\rceil^2}{\overline{12}\rceil^2} \times \overline{\text{KALA}}\rceil^2 = \frac{25}{144} \times \frac{(R^2 - a^2)(R^2 - x^2)}{R^2}$$

$= x^2$

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41. In a place of which the latitude is unknown and on a day which is unknown, the Sun was observed, on entering the prime vertical, to give a shadow of 16 digits from a gnomon (12 digits long) at 8 GHAṬIKÁs after sun-rise. If you will tell me the declination of the Sun, and the PALABHÁ I will hold you to be expert without an equal in the great expanse of the questions on directions space and time.*

Question.

42. O Astronomer, tell me, if you have a thorough knowledge of the latitudinal figures, the PALABHÁ and the longitude of the Sun

Question.

Now $R^2 - a^2 = 8864883$

$25 (R^2 - a^2) = 25 \times 8864883 = 221622075$

and $144 R^2 = 144 (3438)^2 = 1702057536$

$$\therefore \frac{221622075 (R^2 - x^2)}{1702057536} = x^2$$

$$R^2 - x^2 = \frac{1702057536}{221622075} x^2 = 7\tfrac{2}{3} x^2 \text{ nearly}$$

$$\therefore 26 x^2 = 3 R^2 : x^2 = \frac{3 R^2}{26} = 1363828$$

and $x = \sqrt{1363828} = 1167' = \text{sine of } 19° .. 51'$

Hence the Sun's place may be found.—L. W.

* To find the sine of altitude or MAHA' S'ANKU

$(16)^2 + (12)^2 = (20)^2$ ... hypothenuse of the shadow $= 20$.

Then say

As $20 : 12 :: 3438' : 2062' .. 48''$ = the MAHA' S'ANKU.

Now suppose the sine of UNNATA KA'LA or 8 GHAṬIKA's to be the TADDHṚITI $= 2655$.

Then by similar triangles

$$2062' .. 48'' : 2655' :: 12 : \text{AKSHA KARṆA} = \frac{2655' \times 12}{2062\tfrac{4}{5}}$$

From this find the PALABHA'.

To find declination says

As AKSHA KARṆA : PALABHA' :: $2062' .. 48''$: sine of declination.

From this find the cosine of declination, the KUJYA, the ascensional difference, &c. The UNNATA KALA diminished by the ascensional difference gives the time from 6 o'clock : the sine of this time will be the SÚTRA and hence the KALA : thence (KUJYA' being added) the TADDHṚITI : and thence the AKSHA KARṆA and declination. The operation to be repeated till the error of the original assumption vanishes.—L. W.

at that place, where (at a certain time) the KUJYÁ is equal to 245 and the TADDHṚITI is equal to 3125.*

43. Given the sum of the 3 following quantities, viz. of the sines of declination, and of the altitude of the Sun (when in the prime vertical) and of the TADDHṚITI decreased by the amount of the KUJYÁ equal to 6720, and given also the sum of the KUJYÁ, the sines of amplitude and declination (at the same time) equal to 1960. I will hold him, who can tell me the longitude of the Sun and also PALABHÁ from the given sums, to be a bright instructor of astronomers, enlightening them as the Sun makes the buds of the lotus to expand by his genial heat.†

Question.

* Ansr. Let x = the PALABHA

then say. As $x : 12 :: 245$: sine of declination $= \frac{2940}{x}$.

Now find the TADDHṚITI *minus* KUJYA'.

As $x : 12 :: \frac{2940}{x}$: TADDHRITI — KUJYA $= \frac{35280}{x^2}$.

But TADDHRITI — KUJYA $= 3125 - 245 = 2880$.

$\therefore 2880 = \frac{35280}{x^2}$ and $x^2 = \frac{35280}{2880} = \frac{49}{4}$

$\therefore x = \frac{7}{2} = 3\frac{1}{2}$ PALABHA.

To find declination say

As $3\frac{1}{2} : 12 :: 245 : 840$ sine of declination.

Hence the longitude of the Sun may be discovered as before.—L. W.

† This question admits of a ready solution in consequence of its peculiarities.

The sine of declination, SAMA S'ANKU and TADDHṚITI — KUJYA $\}$ = 6720

are all three respectively perpendiculars in the three latitudinal triangles.

And the KUJYA, the sine of amplitude and the TADDHRITI — KUJYA $\}$ = 1960

are bases in the same 3 triangles.

Hence we may take the sum of the 3 perpendiculars and also the sum of the three bases and use them to find the PALABHA.

As the sum of the 3 perpendiculars	sum of the 3 bases in the same triangles	Gnomon	PALABHA
6720 :	1960	:: 12 :	$\frac{1960 \times 12}{6720} = 3\frac{1}{2}$.

Now the KUJYA, sine of amplitude and sine of declination are the three sides of a latitudinal triangle. These three I may compare with the three Gnomon, PALABHA and AKSHA KARṆA to find the value of any one.

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44. Given the sum of the sine of declination, sine of the Sun's altitude in prime vertical and the TADDHṚITI *minus* KUJYÁ equal to 1440′, and given also the sum of the sine of amplitude, the sine of the Sun's altitude in prime vertical and the TADDHṚITI equal to 1800′. I will hold him, who having observed the given sums.*

Question.

45. Given the equinoctial shadow equal to 9. What longitude must the Sun have in that latitude to give an ascensional difference of three GHAṬIS? I will hold you to be the best of astronomers if you will answer me this question.†

Question.

46. Hitherto it has been usual to find the length of the Sun's midday shadow, of the shadow of the Sun when in the prime verti-

Question.

But the AKSHA KARṆA must be first found to complete the sum of those three.

$$\text{AKSHA KARṆA} = \sqrt{(12)^2 + (\tfrac{7}{2})^2} = \sqrt{\frac{625}{4}} = \frac{25}{2}$$

Gnomon = 12
PALABHA = $3\frac{1}{2}$
AKSHA KARṆA = $12\frac{1}{2}$ } = 28 sum of the 3 sides of a latitudinal triangle.

Now if 28 : 12 : : 1960 : 840 the sine of declination.

Hence the place of the Sun as before.—L. W.

* This question is similar to the preceding.

In the first sum we have the sum of three perpendiculars in three different latitudinal Triangles. In the second we have the sum of the three hypothenuses of those same three Triangles. Hence we may say.

	sum 3 per.		sum of 3 corresponding hy.		Gnomon		AKSHAKARṆA
As	1440	:	1800	: :	12	:	15

Now from AKSHA KARṆA to find PALABHÁ

$$\text{PALABHÁ} = \sqrt{(15)^2-(12)^2} = \sqrt{81} = 9.$$

Now sine of amplitude, sine of the Sun's altitude in the Prime Vertical, and the TADDHṚITI are the three sides of a latitudinal.—L. W.

† Let x = sine of the Sun's declination.

then 12 : 9 : : x : KUJYÁ = $\frac{3}{4}x$.

Again $\sqrt{R^2-x^2}$ = cosine of declination.

Then as R : cos of declination : : sine of ascensional difference. : KUJYÁ

Sine of ascensl. diffce. or CHARAJYÁ = sine of 3 GHAṬIS = sin 18° = 1062′.

$$\therefore \frac{\text{cosin of decln.} \times \text{CHARAJYÁ}}{R} = \text{KUJYÁ}$$

$$\text{or} \quad \frac{\sqrt{R^2-x^2} \times 1062}{R} = \tfrac{3}{4}x$$

Hence may be found the sine of the Sun's decln. and thence his longitude.—L. W.

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cal, and when in an intermediate circle (i. e. when he has an azimuth of 45°) by three different modes of calculation: now he who will by a single calculation tell me the length of these three shadows and of the shadows at any intermediate points at the wish of the querist, shall be held to be a very Sun on the Earth to expand the lotus-intellects of learned astronomers.*

* [Here the problem is this:—Given the Sun's declination or amplitude, the Equinoctial shadow of the place and the Sun's azimuth, to find the Sun's shadow.

For solving this problem BHÁSKARÁCHÁRYA has stated two different Rules in the GAṆITÁDHYÁYA. Of them, we now shew here the second.

"Multiply the square of the Radius by the square of the equinoctial shadow, and the square of the cosine of the azimuth by 144. The sum of the products divided by the difference between the squares of the cosine of the azimuth and the sine of the amplitude, is called the PRATHAMA (first) and the continued product of the Radius, equinoctial shadow and the sine of the amplitude divided by the (same) difference is called the ANYA (second). Take the square-root of the square of the ANYA added to the PRATHAMA: this root decreased or increased by the ANYA according as the Sun is in the northern or southern hemisphere gives the hypothenuse of the shadow (of the Sun) when the Sun is in any given direction of the compass."

"But when the cosine of the azimuth is less than the sine of the amplitude, take the square-root of the square of the ANYA diminished by the PRATHAMA: the ANYA decreased and increased (separately) by the square-root (just found) gives the two values of the hypothenuse (of the Sun's shadow) when the Sun is in the northern hemisphere."

This rule is proved algebraically thus.

Let a = the sine of amplitude,
A = the sine of azimuth,
e = the Equinoctial shadow,
and x = the hypothenuse of the shadow when the Sun is in any given direction of the compass.

Then say

as $x : 12 :: R :$ the MAHÁ S'ANKU or the sine of the Sun's altitude $= \frac{12\,R}{x}$

and $\therefore$ the sine of the Sun's zenith distance $= \sqrt{R^2 - \left(\frac{12\,R}{x}\right)^2} = \frac{R}{x}\sqrt{x^2 - 144}$.

Now, as $12 : e = \frac{12\,R}{x} :$ S'ANKUTALA $= \frac{e\,R}{x}$.

$\therefore$ BÁHU or the sine of an arc of a circle of position contained between the Sun and the Prime Vertical $= a \mp \frac{e\,R}{x}$: (see Ch. VII. V. 41) here the sign — or + is used according as the Sun is in the northern or southern hemisphere.

Then say

as $\frac{R}{x}\sqrt{x^2-144} : a \mp \frac{e\,R}{x} :: R : A :$

$$\therefore \frac{R\,A}{x}\sqrt{x^2-144} = \left(a \mp \frac{e\,R}{x}\right) R;$$

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Question.

47. He who, knowing both the azimuth and the longitude of the Sun, observes one shadow of the gnomon at any time, or he who knowing the azimuth observes two shadows and can find the PALABHÁ, I shall conceive him to be a very GARUḌA in destroying conceited snakes of astronomers.

[On this BHÁSKARÁCHÁRYA has given an example in the GAṆITÁDHYÁYA as follows.

Example.

"Given the hypothenuse of the shadow (at any hour of the day) equal to 30 digits and the south BHUJA* equal to 3 digits: given also

or $A \sqrt{x^2 - 144} = a x \mp e R$;

$$A^2 x^2 - 144 A^2 = a^2 x^2 \mp 2 R e a x + e^2 R^2;$$

$$(A^2 - a^2) x^2 \pm 2 R e a x = e^2 R^2 + 144 A^2;$$

$$x^2 \pm 2 \frac{R e a}{A^2 - a^2} x = \frac{e^2 R^2 + 144 A^2}{A^2 - a^2};$$

or $x^2 \pm 2 \text{ ANYA } x = \text{PRATHAMA}$ (1)

$\therefore x^2 \pm 2 \text{ ANYA } x + \text{ANYA}^2 = \text{PRATHAMA} + \text{ANYA}^2$

and $\therefore x = \sqrt{\text{PRATHAMA} + \text{ANYA}^2} \mp \text{ANYA}$.

But when $A \angle a$ and the Sun is in the northern hemisphere, the equation (1) will be $x^2 - 2 \text{ ANYA } x = - \text{PRATHAMA}$,

and then $x = \text{ANYA} \pm \sqrt{\text{ANYA}^2 - \text{first}}$:

i. e. the value of the hypothenuse of the shadow will be of two kinds here.

Hence the Rule.

BHASKARACHARYA was the first Hindu who has given a general rule for finding the Sun's shadow *whatever* be the azimuth; and he was the first who has shewn that in certain cases the solution gives two different results.—B. D.]

* [On a levelled plane draw east and west and south and north lines and on their intersecting point, place Gnomon of 12 digits: the distance between the end of the shadow of that Gnomon and the east and west line is called the BHUJA.

It is to be known here that the value of the great BHUJA (as stated in 41st verse of the 7th Ch.) being reduced to the hypothenuse of the shadow becomes equal to the BHUJA (above found).

Or as the Radius
: the great BHUJA
: : the hypothenuse of the shadow
: the reduced BHUJA or the distance of the end of the shadow from the east and west line.

This reduced BHUJA is called north or south according as the end of the shadow falls north or south of the east and west line.

It is very clear from this that the reduced BHUJA will be the cosine of the azimuth in a small circle described by the radius equal to the shadow.

Or as the shadow
: the reduced BHUJA
: : radius of a great circle
: the cosine of the azimuth.

This is the method by which all Hindus roughly determine the azimuth of the Sun from the BHUJA of his gnomonic shadow.—B. D.]

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the hypothenuse equal to 15 digits, and the north BHUJA equal to 1 digit, to find the PALABHÁ. Or, given the declination equal to 846 and only one hypothenuse and its corresponding BHUJA at the time, to find the PALABHÁ."]

RULE.

48. First of all multiply one BHUJA of the shadow by the hypothenuse of the other, and the second BHUJA by the hypothenuse of the first: then take the difference of these two BHUJAS thus multiplied, if they are both north or if both south, and their sum if of different denominations, and divide the difference or the sum by the difference of the two hypothenuses; it will be the PALABHÁ.*

Question.

49. How should he who, like a man just drawn up from the bottom of a well, is utterly ignorant of the PALABHÁ, the place of the Sun, the points of the compass, the number of the years elapsed from

* The rule mentioned here for finding the PALABHA' when the two shadows and their respective BHUJAS are given, is proved thus,

Let h_1 = the first hypothenuse of the shadow,

b_1 = its corresponding BHUJA,

h_2 = the second hypothenuse,

and b_2 = its corresponding BHUJA,

Then

As $h_1 : 12 :: R : \frac{12\,R}{h_1}$ = the first MAHA S'ANKU ;

and in the same manner $\frac{12\,R}{h_2}$ = the second MAHA S'ANKU ;

and also as $h_1 : b_1 :: R : \frac{b_1\,R}{h_1}$ = the first great BHUJA ,

and ∴ $\frac{b_2\,R}{h_2}$ = the second great BHUJA ,

$$\text{Then the PALABHA'} = \frac{\frac{b_1\,R}{h_1} \mp \frac{b_2\,R}{h_2}}{\frac{12\,R}{h_2} - \frac{12\,R}{h_1}} \text{ (see Ch. XI. V. 32)}$$

$$= \frac{b_1\,h_2 \mp b_2\,h_1}{h_1 - h}$$

Hence the Rule.—L. W.

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the commencement of the YUGA, the month, the TITHI or lunar day and the day of week, being asked by others to tell quickly the points of the compass, the place of the Sun, &c., give a correct answer? He, however, who can do so, has my humble reverence, and what astronomers will not acknowledge him worthy of admiration?*

Question.

50. He, who can know merely with the staff in his hand, the height and distance of a bamboo of which he has observed the root and top, knows the use of that instrument of instruments—Genius (the DHÍYANTRA): and tell me what is there that he cannot find out!

Question.

51. There is a high famous bamboo, the lower part of which, being concealed by houses, &c. was invisible: the ground, however, was perfectly level. If you, my friend, remaining on this same spot, by observing the top, will tell me the distance and its height, I acknowledge you shall have the title of being the most skilful of observers, and expert in the use of the best of instruments, DHÍYANTRA.

Question.

52. Having seen only the top of a bamboo reflected in water, whether the bamboo be near or at a distance, visible or invisible, if you, remaining on this same spot, will tell me the distance and height of the bamboo, I will hold you, though appearing on the Earth as a plain mortal, to have attributes of superhuman knowledge.†

53. Given the places of the Sun and the Moon increased by the amount of the precession of the equinox, i. e. their longitudes, equal to four and two signs (respectively) and the place of the Moon decreased by the place of the ascending node equal to 8 signs, tell me whether the Sun and the Moon have the same declination (either both south or one north

* This refers to the 34th verse of the Ch. XI.—L. W.

† [Answers to these questions will be found in the 11th Ch. —B. D.]

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and one south), if you have a perfect acquaintance with the DHÍVRIDDHIDA TANTRA.

54. If the place of the Moon with the amount of the precession of the equinox be equal to 100 degrees, and the place of the Sun increased by the same amount to 80 degrees, and the place of the Moon diminished by that of the ascending node equal to 200 degrees, tell me whether the Sun and the Moon have the same declination, if you have a perfect acquaintance with the DHÍVRIDDHIDA TANTRA.

55. If you understand the subject of the PÁTA i. e. the equality of the declinations (of the Sun and the Moon), tell me the reason why there is in reality an impossibility of the PÁTA when there is its possibility (in the opinion of LALLA), and why there is a possibility when there is an impossibility of it (according to the same author).

56. If the places of the Sun and the Moon with the amount of the precession of the equinox be equal to 3 signs *plus* and *minus* 1 degree (i. e. 2*s*. 29° and 3*s*. 1° respectively) and the place of the Moon decreased by that of the ascending node equal to 11*s*. 28°, tell me whether the Sun and the Moon have the same declination, if you perfectly know the subject.

57. (In the DHÍVRIDDHIDA TANTRA), it is stated that the PÁTA *is to come* in some places when it has already taken place (in reality), and also it *has happened* where it *is to come*. It is a strange thing in this work when the possibility and imposibility of the PÁTA are also reversely mentioned. Tell me, O you best of astronomers, all this after considering it well.*

Date of the Author's birth and his work.

58. I (BHÁSKARA), born in the year of 1036 of the S'ÁLIVÁHANA era, have composed this SIDDHÁNTA-S'IROMANI, when I was 36 years old.

Author's apology.

59. He who has a penetrating genius like the sharp point of a large DARBHA straw, is qualified to compose a good work in mathe-

* [Answers to these questions will be found in the last Chapter of the GANITADAYAYA.—B. D.]

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matics: excuse, therefore, my impudence, O learned astronomers, (in composing this work for which I am not qualified).

60. I, having lifted my folded hands to my forehead, beg the old and young astronomers (who live at this time) to excuse me for having refuted the (erroneous) rules prescribed by my predecessors; because, those who fix their belief in the rules of the predecessors will not know what is the truth, unless I refute the rules when I am going to state astronomical truths.

Author's birth-place, &c.

61. The learned Mahes'wara, the head of all astronomers, the most good humoured man, the store of all sciences, skilful in the discussion of acts connected with law and religion, and a bráhmaṇa descended from S'áṇḍilya (a muni), flourished in a city, thickly inhabited by learned and dull persons, virtuous men of all sorts, and men competent in the three Vedas, and situated near the mountain Sahya.

62. His son, the poet and intelligent Bháskara, made this clear composition of the Siddhánta by the favour of the lotus-like feet of his father; this Siddhánta is the guidance for ignorant persons, propagator of delight to the learned astronomers, full of easy and elegant style and good proofs, easily comprehensible by the learned, and remover of mistaken ideas.

63. I have repeated here some questions, which I have stated before, for persons who wish to study only this Pras'nádhyáya.

64. The genius of the person who studies these questions becomes unentangled, and flourishes like a creeping plant watered at its root by the consideration of the questions and answers, by getting hundreds of leaves of clear proofs, shooting from the Spheric as from a bulbous root.

End of the 13th and last Chapter of the Goládhyáya of the Siddhánta-s'iromaṇi.

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APPENDIX.

ON THE CONSTRUCTION OF THE CANON OF SINES.

1. As the Astronomer can acquire the rank of an ÁCHARYA in the science only by a thorough knowledge of the mode of constructing the canon of sines, BHÁSKARA therefore now proceeds to treat upon this (interesting and manifold) subject in the hope of giving pleasure to accomplished astronomers.

2 and 3. Draw a circle with a radius equal to any number of digits: mark on it the four points of the compass and 360°. Now by dividing 90° by the number of sines (you wish to draw in a quadrant), you will get the arc of the first sine. This arc, when multiplied by 2, 3 &c., will successively be the arcs of other sines. Now set off the first arc on the circumference on both sides of one of the points of the compass and join the extremities of these arcs by a transverse straight line, the half of which should be known the sine of the first arc: All the other sines are thus to be known.

4. Or, now, I proceed to state those very sines by mathematical precision with exactness. The square-root of the difference between the squares of the radius and the sine is cosine.

5. Deduct the sine of an arc from the radius the remainder will be the versed sine of the complement of that arc, and the cosine of an arc deducted from the radius will give the versed sine of that arc. The versed sine has been compared to the

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arrow between the bow and the bow-string: but here it has received the name of versed-sine.

6. The half of the radius is the sine of 30°: the cosine of 30° will then be the sine of 60°. The square-root of half square of radius will be the sine of 45°.

7. Deduct the square-root of five times the fourth power of radius from five times the square of radius and divide the remainder by 8: the square-root of the quotient will be the sine of 36°.

$$\text{Or } \sqrt{\frac{\text{rad}^2 \times 5 - \sqrt{\text{rad}^4 \times 5}}{8}} = \text{sine } 36^\circ.*$$

8. Or the radius multiplied by 5878 and divided by 10000 will give the sine of 36°, (where the radius = 3438.) The cosine of this is the sine of 54°.†

9. Deduct the radius from the square-root of the product of

* [This is proved thus.

Let a = sine 18°; and ∴ R − a = covers 18° or vers 72°.

$$\text{Then } \sqrt{\frac{R \times \text{vers } 72^\circ}{2}} = \text{sine } \tfrac{72}{2}^\circ: \text{ (see the 10th verse.)}$$

$$\text{or } \sqrt{\frac{R\,(R - a)}{2}} = \text{sine } 36^\circ;$$

$$\text{but } a = \frac{\sqrt{5\,R^2} - R}{4} \text{ (see the 9th verse)}$$

$$\therefore \text{ sine } 36^\circ = \sqrt{\frac{R\left\{R - \tfrac{1}{4}\left(\sqrt{5\,R^2} - R\right)\right\}}{2}} = \sqrt{\frac{5\,R^2 - \sqrt{5\,R^4}}{8}}.\text{B. D.]}$$

† The Rule in 8th verse viz., $\frac{R \times 5878}{10000}$ seems to be the same as above and to be deduced from it;

$$\text{for } \sqrt{\frac{5\,R^2 - \sqrt{5\,R^4}}{8}} = R.\sqrt{\frac{5 - \sqrt{5}}{8}}$$

$\sqrt{5}$ = 2.237411 &c.

and ∴ 5 − $\sqrt{5}$ = 2.762589 which divided by 8 = .345323

$$\therefore \text{ sine } 36^\circ = R\,\sqrt{.345323} = R \times .5878 = \frac{R \times 5878}{10000}.\text{—L. W.}$$

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the square of radius and five and divide the remainder by 4: the quotient thus found will give the exact sine of 18°.*

10. Half the root of the sum of the squares of the sine and versed sine of any arc, is the sine of half that arc. Or, the sine of half that arc is the square-root of half the product of the radius and the versed sine.

11. From the sine of any arc thus found, the sine of half the arc may be found (and so on with the half of this last). In like manner from the complement of any arc may be ascertained the sine of half the complement (and from that again the sine of half of the last arc).

Thus the former Astronomers prescribed a mode for determining the other sines (from a given one), but I proceed now to give a mode different from that stated by them.

12. Deduct and add the product of radius and sine of BHUJA from and to the square of radius and extract the square-roots of the halves of the results (thus found), these roots will respectively give the sines of the half of 90° decreased and increased by the BHUJA.

In like manner, the sines of half of 90° decreased and increased by the KOṬI can be found from assuming the cosine for the sine of BHUJA.

13. Take the sines of BHUJAS of two arcs and find their difference, then find also the difference of their cosines, square

* [This is proved thus.

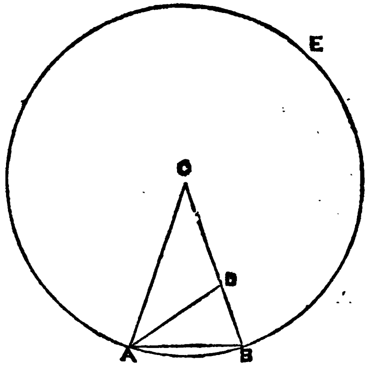
Let C be centre of the circle ABE and $\angle$ C = 36°, then AB = 2 sin 18°, and $\angle s$ (CAB, CBA) each of them = 2 C.

Draw AD bisecting the $\angle$ CAB, then AB, AD, CD will be equal to each other.

Now let x = sin 18°, then by similar triangles CB : AB = AB : BD or R : 2 x = 2 x : R — 2 x;

$\therefore 4x^2 = R^2 - 2Rx$ which gives

$x = \frac{\sqrt{5R^2} - R}{4}$.—B. D.]



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these differences, add these squares, extract their square-root and halve it. This half will be the sine of half the difference of the sines.* Thus sines can be determined by several ways.

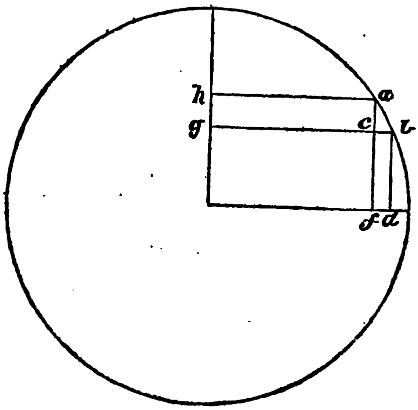
14. The square-root of half the square of the difference of the sine and the cosine of the BHUJA of an arc is equal to the sine of half the difference of the BHUJA and its complement.†

I will now give some rules for constructing sines without having recourse to the extraction of roots.

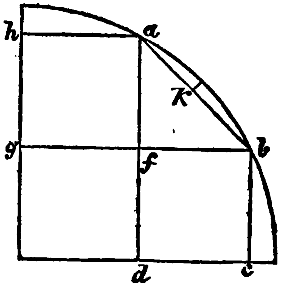
15. Divide the square of the sine of the BHUJA by the half radius. The difference between the quotient thus found and the radius is equal to the sine of the difference between the

* This rule is obvious,
for ac = diffce. of sines bd & af
and cb = diffce. of cosines bg & ah
and $\overline{ac}\rceil^2 + \overline{bc}\rceil^2 = \overline{ab}\rceil^2$
ab = chord of difference of arcs
$\frac{ab}{2}$ = sine of half that difference.

L. W.



† Let bc = sine of any arc and bg = its cosine.
Draw the sine ad = cosine bg, then ah its sine will be equal to bc and $af = fb$:
$\therefore af^2 + fb^2 = ab^2$: but as $af^2 = fb^2$
$\therefore af^2 = \frac{ab^2}{2}$ and $\frac{af^2}{2} = \frac{ab^2}{4}$:
$\therefore \sqrt{\frac{af^2}{2}} = \frac{ab}{2}$.—L. W.]



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degrees of BHUJA and its complement.* In this way several sines may be found here.

[As these several rules suffice for finding only the sines of arcs differing by 3 degrees from each other and not the sines of the intermediate arcs, the author therefore now proceeds to detail the mode of finding the intermediate sines, that is the sine of every degree of the quadrant. This mode, therefore, is called PRATIBHÁGAJYAKÁ-VIDHI.]

Rules for finding the sine of every degree from 1° to 90°.

16. Deduct from the sine of BHUJA its $\frac{1}{6569}$ part and divide the ten-fold sine of KOṬI by 573.

17. The sum of these two results will give the following sine (i. e., the sine of BHUJA one degree more than original BHUJA and the difference between the same results will give the preceding sine, i. e., the sine of BHUJA one degree less than original BHUJA). Here the first sine, i. e., the sine of 1°, will be 60 and the sines of the remaining arcs may be successively found.

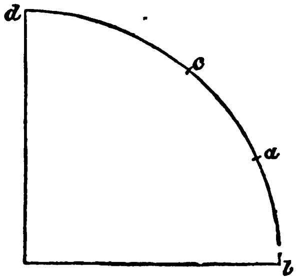
18. The rule, however, supposes that the radius = 3438. Thus the sines of 90° of the quadrant may be found.

Multiply the cosine by 100 and divide the product by 1529.

Rules for finding the 24 sines viz., of 3°¾, 7°½, 11°¼, 15°, &c.

19. And subtract the $\frac{1}{467}$ part of the sine from it. The sum of these will be the following sine (i. e., the sine of arc of 3°¾ degrees more than original arc): and the differ-

* Let *ab* be any arc, and *ac* = *ab*, then *ad* = its complement, *cd* = their difference, and *bc* = 2 *ab*.



Now $\sqrt{\frac{R \times \text{vers } bc}{2}} = \sin \frac{bc}{2}$ or $\sin ab$,

or $\frac{R \times \text{vers } bc}{2} = \sin^2 ab$,

or $\text{vers } bc = \frac{2 \sin^2 ab}{R}$,

then $R - \text{vers } bc$ or $\sin cd = R - \frac{\sin^2 ab}{\frac{1}{2} R}$.—L. W.

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ence of them will be preceding sine (i. e., the sine of arc $3^o\frac{3}{4}$ degrees less than original arc).

20. But the first sine (or the sine of $3_o\frac{3}{4}$) is here equal to $224\frac{6}{7}$ (and not to 225 as it is usually stated to be). By this rule 24 sines may be successively found.*

Rules for finding the sines of sum and difference of any two arcs.

21 and 22. If the sines of any two arcs of a quadrant be multiplied by their cosines reciprocally (that is the sine of the first arc by the cosine of the 2d and the sine of the 2d by the cosine of the first arc) and the two products divided by radius, then the quotients will, when added together, be the sine of the sum of the two arcs, and the difference of these quotients will be the sine of their difference.† This excellent rule called JYA-BHÁVANÁ has been prescribed for ascertaining the other sines.

23. This rule is of two sorts, the first of which is called SAMÁSA-BHÁVANÁ (i. e., the rule for finding the sine of sum of two arcs) and the second ANTARA-BHÁVANÁ (i. e., the rule to find the sine of difference of arcs).

[If it be desired to reduce the sines to the value of any other radius than that above given of 3438.] Find the first sine by the aid of the above-mentioned rule PRATIBHÁGAJYAKÁ-VIDHI.

24 and 25. And then reduce it to the value of any new radius by applying the proportion. After that apply the JYÁ-BHÁVANÁ rule through the aid of the first sine and the cosine thus found, for as many sines as are required. The sines will thus be successively eliminated to the value of any new radius.

The rule given in my PATÍ or LÍLÁVATÍ is not sufficiently accurate (for nice calculations) I have not therefore repeated here that rough rule.

* [These rules given in the verses from 16 to 20 are easily deduced from the rules given in the verses 21 and 22.—B. D.]

† BHÁSKARÁCHÁRYA has given these rules in his work without any demonstration.—B. D.]

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